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Unveiling a greener world:
assessing foresting commitments and projects about their economic and mitigation potentials

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Unveiling a greener world: assessing foresting commitments and projects about their economic and mitigation potentials

Remo Augusto Padovezi Filleti

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To my beloved family in Brazil, who always supported my decisions…

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Nothing ventured, nothing gained. Seeking for a PhD is already a great challenge by itself, but to go for one in another country is even more challenging. Distance from family and language barriers are some of the obstacles someone must face in a different country. Despite these difficulties, the benefits from doing such entrepreneurship were overwhelmingly higher.

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“... A minha mãe naquele dia
Me falou do mundo como ele é
Parece que ela conhecia
Cada pedra que eu iria pôr o pé
E sempre ao lado do meu pai
Da pequena cidade ela jamais saiu

Ela me disse assim:
Meu filho, vá com Deus
Que este mundo inteiro é seu ...”

No dia em que eu saí de casa - Joel Marques

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LIST OF ACRONYMS

ABC	Low Carbon Agriculture program (*"Programa para Agricultura de Baixo Carbono"*, in Portuguese);
AEZ	Agro-Ecological Zones;
AFR100	African Forest Landscape Restoration Initiative;
APP	Permanent Preservation Area (*“Área de Preservação Permanente”*, in Portuguese);
B_Africa	Region composed by African countries which are part of the Bonn Challenge effort;
B_Asia	Region composed by Asian countries which are part of the Bonn Challenge effort;
B_LatinAmer	Region composed by Latin American countries which are part of the Bonn Challenge effort;
B_NAmer	Region composed by North American countries which are part of the Bonn Challenge effort;
BAU	Business as Usual;
BEP	Biomass for Energy Purposes;
BNDES	Brazilian Development Bank (*“Banco Nacional de Desenvolvimento Econômico e Social”*, in Portuguese);
BRL	Brazilian Reais (or R$);
CAR	Environmental Rural Register program (*"Cadastro Ambiental Rural"*, in Portuguese);
CDM	Clean Development Mechanism from Kyoto Protocol;
CET	Constant Elasticity of Transformation function;
CGE	Computable General Equilibrium model;

COP	Conference of the Parties;
COFINS	Contribution for Social Security Financing (*"Contribuição para o Financiamento da Seguridade Social"*, in Portuguese);
CSLL	Social Contribution over Net Profit (*"Contribuição Social sobre o Lucro Líquido"*, in Portuguese);
CERs	Certified Emission Reductions;
DBH	Diameter at Breast Height;
DCL	Business scenario considering wood debris (D) as biomass for energy purposes, carbon credits accounting (C) and targeting local market (L);
DCE	Business scenario considering wood debris (D) as biomass for energy purposes, carbon credits accounting (C) and targeting external market (E);
DXL	Business scenario considering wood debris (D) as biomass for energy purposes, NO carbon credits accounting (X) and targeting local market (L);
DXE	Business scenario considering wood debris (D) as biomass for energy purposes, NO carbon credits accounting (X) and targeting external market (E);
EU27	European Union composition from 1 Jan 2007 to 30 June 2013;
FAO	Food and Agriculture Organization of the United Nations;
FNMA	National Fund for Environment (*"Fundo Nacional do Meio Ambiente"*, in Portuguese);
Funrural	Assistance to the Rural Worker Program (*"Fundo de Assistência ao Trabalhador Rural"*, in Portuguese);
GDP	Gross Domestic Product;
GFBs	Green Forest Bonds;
GHG	Greenhouse Gas;

GFBs	Green Forest Bonds;
GTAP	Global Trade Analysis Project;
IBAMA	Brazilian Institute of the Environment and Renewable Natural Resources (*“Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis”*, in Portuguese);
ICES	Intertemporal Computable Equilibrium System;
ICMS	State Tax over the Circulation of Goods and Services (*“Imposto sobre Circulação de Mercadorias e prestação de Serviços”*, in Portuguese);
INCT-L	Brazilian National Index for Transportation Costs from Non-Fractionated Loads (*“Índice Nacional do Custo de Transporte de Carga - Lotação”*, in Portuguese);
IRPJ	Corporate Income Tax (*“Imposto sobre a Renda das Pessoas Jurídicas”*, in Portuguese);
IRR	Internal Rate of Return;
ITTO	International Tropical Timber Organization;
IUCN	International Union for Conservation of Nature;
LGP	Length of Growing Periods;
LUCF	Land Use Change and Forestry;
MCTIC	Brazilian Ministry of Science, Technology, Innovation and Communication (*"Ministério da Ciência, Tecnologia, Inovações e Comunicações"*, in Portuguese);
NB_Africa	Region composed by African countries which are NOT part of the Bonn Challenge effort;
NB_Asia	Region composed by Asian countries which are NOT part of the Bonn Challenge effort;

NB_LatinAmer	Region composed by Latin American countries which are NOT part of the Bonn Challenge effort;
NB_NAmer	Region composed by North American countries which are NOT part of the Bonn Challenge effort;
NAMAs	Nationally Appropriate Mitigation Actions;
NBSAP	National Biodiversity Strategy and Action Plan;
NDCs	Nationally Determined Contributions;
NPV	Net Present Value;
PCL	Business scenario considering pellets (P) as biomass for energy purposes, carbon credits accounting (C) and targeting local market (L);
PCE	Business scenario considering pellets (P) as biomass for energy purposes, carbon credits accounting (C) and targeting external market (E);
PIS	Contribution to the Social Integration Plan (*"Programa de Integração Social"*, in Portuguese);
PLANAVEG	National Plan for the Recuperation of Native Vegetation (*"Plano Nacional de Recuperação da Vegetação Nativa*", in Portuguese);
PNDF	National Plan for the Development of Planted Forests (*"Plano Nacional de Desenvolvimento de Florestas Plantadas"*, in Portuguese);
PNMC	National Policy on Climate Change (*"Política Nacional sobre Mudanças Climáticas"*, in Portuguese);
PRONAF	National Program for Strengthening of the Family Agriculture (*"Programa Nacional de Fortalecimento da Agricultura Familiar"*, in Portuguese);
PRONAMP	National Program to Support the Medium Rural Producer (*"Programa Nacional de Apoio ao Médio Produtor Rural"*, in Portuguese);

PROVEG	National Policy for Recuperation of Native Vegetation (*"Política Nacional de Recuperação da Vegetação Nativa"*, in Portuguese);
PXL	Business scenario considering pellets (P) as biomass for energy purposes, NO carbon credits accounting (X) and targeting local market (L);
PXE	Business scenario considering pellets (P) as biomass for energy purposes, NO carbon credits accounting (X) and targeting external market (E);
RL	Legal Reserve (*“Reserva Legal”*, in Portuguese);
SEEG Brasil	Brazilian System for Greenhouse Gas Emissions and Removals Estimates (*"Sistema de Estimativas de Emissões e remoções de Gases de efeito estufa"*, in Portuguese);
SFM	Sustainable Forest Management;
SSP2	Shared Socio-economic Pathway 2;
tCERs	temporary Certified Emission Reductions;
UN	United Nations;
UNCCD	United Nations Convention to Combat Desertification;
UNECE	United Nations Economic Commission for Europe;
UNEP CBD	United Nations Environment Programme Convention on Biological Diversity;
UNFCCC	United Nations Framework Convention on Climate Change;
USD	United States Dollars (or $).

LIST OF SYMBOLS

$\Delta\boldsymbol{AEZ_{i,R}^{F,C,L}}$	Absolute variation of AEZ_i for sectors F, C, L at region R [ha];
$\%\boldsymbol{AEZ_{i,R}^{C,L}}$	Relative variation of AEZ_i for sectors C, L at region R [%];
$\mathbf{E_t}$	Expenses (i.e., costs and taxes) at time **t** [USD];
F, C, L	Land intensive sectors: Forestry, Crops and Livestock grazing [-];
$\mathbf{F_t}$	Cash flow at time **t** [USD];
h	Tree height [m];
i	Number of AEZ, from 1 up to 18 [-];
$\mathbf{I_t}$	Income at time **t** [USD];
n	Number of trees per hectare: 555 for accessory species and 833 for main species [-/ha];
$\boldsymbol{\pi}$	3.1415... [-];
r	Discount rate [-];
R	Region [-];
t	Time [year];
T	Harvesting final year [year];
$\mathbf{T_s}$	Shock year, from 2011 until 2030 [year];
$\mathbf{V_A}$	Total tree volume per area [m^3/ha];
$\mathbf{V_p}$	Parabolic volume for a single tree [m^3].

CONTENTS

1 EXECUTIVE SUMMARY

This PhD thesis is structured as a collection of in three individual essays, aiming to investigate the economic and mitigation potentials from growing forests in three different levels: national, local and global.

As a starting point, the first essay frames the thesis objective by performing a policy analysis regarding the implementation of Brazil's Nationally Determined Contribution of restoring and reforesting 12 million hectares of new forests by 2030, for multiple purposes. By using the term "multiple purposes", the commitment is unclear about how much forest area should be restored (returned to the original "reference" ecosystem) and/or reforested (covered by trees).

Restoration projects are more complex and costly compared with reforestation ones, especially when tree monocultures are considered. Yet, restoration projects are more efficient in providing ecosystem services and serving as persistent carbon pools. This undefinition about how and which forestation activities should be implemented led to the development of different approaches by interested parties, in particular the Brazilian Ministry of Environment, World Bank, Instituto Escolhas and the Brazilian Ministry of Science, Technology, Innovation and Communication.

The essay scrutinizes these different approaches, identifying the hotspots and policy recommendations regarding the pathway for implementation, total costs, carbon sequestration potential and financial support. Among the recommendations, splitting the forestation total target in two sub-targets, one for reforestation and one for forest restoration, is key to clear the scenario for the design dedicated pathways and action plans for each forestation technique.

In addition, the full implementation of the Environmental Rural Register program (CAR) should be prioritize, as it will provide detailed mapping regarding the degraded areas, allowing more confident estimations for foresting target implementing costs and mitigation potential. Where possible, natural regeneration must be prioritized over the other forest recovery techniques, as its costs are just a fraction from the others and its implementation much less complex. Regarding financial support, the development of green forest bonds arises as the best solution to mobilize the resources needed to finance Brazilian Nationally Determined Contribution for forestation without compromising the country's sensitive fiscal situation.

The second essay consists a detailed economic analysis from a mixed exotic-native forestry case study sited in the Brazilian Atlantic Forest biome. Eight different forest business scenarios were evaluated, considering different forest-based products (sawn wood, wood debris or

pellets), carbon credit accounting and different target markets (national and international). Economic parameters such as costs, tax regimes, revenues, net present values, internal rates of return and payback period were assessed for each scenario. The results indicate the importance of tax regime to this type of project, particularly the fiscal advantages provided to the international.

The scenarios remained economically robust regarding variation of sawn wood prices. Transforming wood debris in pellets had positive but low impact on the internal rate of return. Carbon credits also contributed little to the economic results, but it may become a relevant source of revenues with the rise on carbon prices. Despite the risks involving the long-term nature of this type of project, some scenarios presented interesting economic results, offering internal rates of returns close to 16%, similar to the ones Pinus monocultures in Brazil.

Finally, by means of a computable general equilibrium model, the third essay addresses the economic impacts from the fulfillment of global initiative to restore 350 million hectares of forests by 2030, known as Bonn Challenge. This work evaluates the effects caused by the implementation of this initiative regarding relative changes in land prices, total production and market prices of land intensive sectors (forestry, crops and livestock grazing). Similarly, impacts on regional Gross Domestic Product (GDP) were also assessed.

The results show non-marginal variation on land prices by the implementation of the restoration effort, particularly at African countries under the initiative, which presented land prices rises from 35.72% up to 105.94%. Similar price variations were also found for forestry, crops and livestock products.

With regard to the effects in GDP, the accumulated variation of GDP ranged from -0.8% to 0% in most regions, both under or out Bonn Challenge initiative. The work concludes that, in order to fairly share the economic impacts from Bonn Challenge’s implementation, the restoration activities should be more evenly distributed across the world, reducing the burden of developing regions, in special African countries.

Keywords: Forest economics, Mitigation, Forest policy, Forestry

2 RESTORING AND REFORESTING 12 MILLION HECTARES OF FORESTS BY 2030: POLICY INSIGHTS TO ACHIEVE BRAZILIAN NATIONALLY DETERMINED CONTRIBUTION TARGET FOR FORESTATION

2.1 Introduction

On 21th September of 2016, Brazilian government submitted its first Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change Registry (UNFCCC, 2018), just two weeks before the conditions for the entry into force of Paris Agreement were met (UN, 2016).

According to its NDC, Brazil commits to reduce greenhouse gas emissions by 37% below 2005 levels in 2025 and 43% below 2005 levels in 2030 (Federative Republic of Brazil, 2015). In absolute terms, Brazil set an emission cap of 1.34 $GtCO_{2eq}$ by 2025, and of 1.20 $GtCO_{2eq}$ by 2030 (Brazilian Ministry of Environment, 2015).

To achieve such results, mitigation actions are focused in four different sectors: energy (including transportation), industry, agriculture, and land use change and forestry – LUCF (Federative Republic of Brazil, 2015).

Among these sectors, LUCF is the most relevant one. Brazil has approximately 493.5 million hectares of forest cover (~58% of national territory), from which 485.7 million hectares consist of native forests and 7.8 million hectares of planted ones (Brazilian Forestry Service, 2017; FAO, 2015; IBÁ, 2017).

Despite the great amount of forest, its area has been rapidly decreasing. From 1990 to 2010, 55 million hectares of forest were cleared, mostly concentrated at Amazon Forest and Cerrado biomes, pushed by squatting, illegal logging and expansion of the farming activities (Espírito-Santo et al., 2016; Fearnside, 2017; IPAM, 2017; Noojipady et al., 2017). According to Brazilian System for Greenhouse Gas Emissions and Removals Estimates (SEEG Brasil, 2018), during this period, gross emissions from LUCF accounted for 33.2 GtCO2eq, or 66.1% all Brazilian emissions (SEEG Brasil, 2018).

In 2017, LUCF still accounted for 51.25% of Brazilian greenhouse gas (GHG) gross emissions in 2016 (~1.17 $GtCO_{2eq}$), most of it from deforestation and forest degradation. LUCF also represented Brazilian major carbon sink in the same year, retrieving about 0.53 $GtCO_{2eq}$ from atmosphere, resulting in a net emission of 0.64 $GtCO_{2eq}$ (SEEG Brasil, 2018).

From this scenario, it is reasonable to presume that the expansion of forest coverage and, consequently the enhancement of forests carbon stock and sink capabilities are of crucial support for Brazil to achieve relevant reduction of GHG net emissions.

In fact, even before its NDCs' submission, Brazil already addressed forest restoration/reforestation in international agreements and national policies. Brazil is currently committed with the voluntary Nationally Appropriate Mitigation Actions – NAMAs (Federative Republic of Brazil, 2010a) and the 20 National Biodiversity Targets part of the United Nations Environment Programme Convention on Biological Diversity - UNEP CBD (Brazilian Ministry of Environment, 2013), which include reforestation and/or forest restoration among their objectives. At the national level, the domestic ground to pursue forest expansion is set by the New Forest Code (Federative Republic of Brazil, 2012) and the National Agricultural Policy on Forestry (Federative Republic of Brazil, 2014)

Within the framework of the NDCs, the country introduced significant measures for deforestation avoidance, native forest monitoring and forestation. Aligned with other developing countries like China, India, Ethiopia and Bolivia (Federal Democratic Republic of Ethiopia, 2015; People's Republic of China, 2015; Plurinational State of Bolivia, 2015; Republic of India, 2015), Brazil presented one of the most ambitious commitments for forest expansion, aiming to restore and reforest 12 million hectares of forests by 2030, for multiple purposes (Federative Republic of Brazil, 2015).

It is important to highlight that, even though there is no explicit definition for "restore" and "reforest" in the Brazilian NDCs document, they represent different concepts. Forest restoration refers to the return of an ecosystem as close as possible to the original "reference" ecosystem, while reforestation represents a broader concept and refers to any process that returns complete or partial tree cover on forest land through planting or through natural or assisted regeneration processes, including commercial forests (World Bank, 2017).

From an economic perspective, restoration projects are much more complex and costly than reforestation ones, especially when compared with monoculture reforestation (e.g., Eucalyptus or Pinus). Yet, restoration projects are more efficient in providing ecosystem services and serving as persistent carbon pools.

The generality of the terms used to define the target creates ambiguity about which type of forest should be prioritized and how to proceed with the target fulfilment. In addition, Brazilian NDCs document is not clear about how the forestation commitment complements and/or overlaps the other ongoing forestation policies. Notwithstanding the absence of directness, Brazilian NDC for forestation has been assessed by some interested parts (i.e., Brazilian governmental bodies, civil society organizations and international institutions), which developed a set of independent studies about how to fulfill the pledge.

By scrutinizing these studies, the present chapter aims to shed light on the commitment implementation, policies costs and benefits associated to the Brazilian forestation NDC. Furthermore, it identifies a set of policy recommendations to support the forestation of 12 million hectares by 2030.

First, an overview of Brazilian ongoing forestation commitments and polices is presented to assess how and to which extend they could interact with the forestation NDC. Secondly, four different studies were evaluated regarding the implementation schedule, total costs, mitigation potential and financial support to Brazilian forestation goal - one from the Brazilian Ministry of Environment, one from Instituto Escolhas[1], one from the World Bank, and one from Brazilian Ministry of Science, Technology, Innovation and Communication. Based on these assessments, it was possible to identify the merits and limitations of each study and/or policy, spotting the most relevant measures and mechanisms that would foster the successful implementation of the NDC for forestation.

This chapter is divided as follows. Section 2.2 introduces the pre-NDC Brazilian forestation commitments and current forest policies. Section 2.3 assesses the Brazilian forestation NDC target and the four selected studies to achieve it. Section 2.4 elaborates policy recommendations regarding NDC forestation pathway, total costs, carbon sequestration potential and financial support. Conclusion and outlooks are presented by Section 2.5.

2.2 Brazilian forestation commitments and policies

2.2.1 Nationally Appropriate Mitigation Actions

On 29th January 2010, just after the 2009 Conference of the Parties (COP15) of the UNFCCC, the Brazilian government officially notified the UNFCCC parties about its voluntary NAMAs (Federative Republic of Brazil, 2010a). The notification consisted of eleven different mitigation actions which would result from 36.1% to 38.9% reduction of the projected national GHG emissions by 2020.

On national level, Brazilian NAMA's were officialized and regulated by the National Policy on Climate Change – PNMC (Federative Republic of Brazil, 2009, 2010b). Beyond the eleven NAMA's, PNMC set the national directives and guidelines to balance socio-economic development with the climate system protection.

Within the PNMC structure, a National Plan on Climate Change and nine different sectorial plans for climate change mitigation and adaptation were established. The covered sectors were energy, agriculture, mining, manufacturing industry, steel industry, transportation, health system and forest sector, the latter with two different plans.

The National Plan on Climate Change stated that reforestation activities should be promoted as a measure to eliminate the country's forest cover net loss. The initial proposal was to increase the total area of planted forests from 5.5 million to 11 million hectares (by 2020), 2 million hectares of which should use just native tree species (Federative Republic of Brazil, 2008).

The presidential decree that regulates the PNMC (decree 7.390, from 9th December 2010 - Federative Republic of Brazil, 2010b) later changed this forest expansion proposal to an overall target of 3 million hectares of new reforested areas, in line with the target from the sectorial plan for agriculture (Brazilian Ministry of Agriculture Livestock and Food Supply, 2012).

The main objective of this expansion, besides the capture of CO_2 from atmosphere, was to increase the offer of timber for multiple uses, reducing the pressure over native forests. The investment for the implementation of this reforestation commitment was estimated in 4.54 billion of dollars[2] (approximately $1,514.80 per hectar[2] - Brazilian Ministry of Agriculture Livestock and Food Supply, 2012).

Despite the sectorial plans for forests were the most important instruments to achieve the PNMC objectives, they were mainly focused on avoiding deforestation from Amazon and Cerrado biomes, and had no defined targets regarding reforestation or forest restoration (Brazilian Ministry of Environment, 2016).

Another reforestation target was defined by an executive summary of the sectorial plan for steel industry. This plan projected an expansion of 2 million hectares in reforested areas for energy purposes (i.e., charcoal production and consumption). By this measure, it is expected an emission reduction of 2.65 $MtCO_{2eq}$ due the decreased pressure over native forests and investments around 3.13 billion of dollars[2] (approximately $1,566.47 per hectar[2] - Brazilian Ministry of Industry Foreign Trade and Services, 2010). The final version of this sectorial plan is not available yet, so it is still open whether this new target will be additional or not to PNMC.

Anyway, also the fulfilment of the current PNMC reforestation target is unlikely. From 2010[3] to 2017, the area of planted forests increased just 1.4 million hectares, an average of 200 thousand of new hectares per year (IBÁ, 2017, 2018). To achieve the 3 million hectares by the end of 2020, the average yearly expansion should be around 533 thousand hectares from 2018 to 2020, about 2.7 times higher than the current one.

In sum, differently from the Brazilian NDC for forestation, the forestation measures included in the Brazilian NAMA's are concentrated just in increasing the area of planted forests and don't cover any restoration measures. Moreover, considering the current reforestation rate, the achievement of 3 million hectares of new planted forests by 2020 is highly uncertain.

2.2.2 Nationally Biodiversity Targets

In line with the Global Biodiversity Targets (aka Aichi Biodiversity Targets) defined during the 10th Conference of the Parties - COP10 (UNEP, 2010) from UNEP CBD, Brazilian government established the 20 National Biodiversity Targets for the period 2011-2020 (Brazilian Ministry of Environment, 2013).

These targets pursue the mitigation of biodiversity loss by addressing its underlying causes, promoting the sustainable use of biodiversity, and safeguarding ecosystems, species and genetic diversity. Directives and guidelines were covered by the National Biodiversity Strategy and Action Plan – NBSAP (Brazilian Ministry of Environment, 2017a).

Forests play a key role on the country's biological diversity. Brazil has six different biomes (i.e., Caatinga, Cerrado, Pantanal, Amazon Forest, Atlantic Rainforest and Pampas), from which two of them, i.e., Atlantic Rainforest and Cerrado, are biodiversity hotspots (Myers et al., 2000).

This great variety of biomes in association with a large coastline make Brazil the most biodiverse country in the world, fostering approximately 20% of all planet's biodiversity (Brazilian Ministry of Environment, 2017a).

Among the twenty different Brazilian biodiversity targets, Target 15 addresses the forest/ecosystem restoration actions. It states:

> By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced through conservation and restoration actions, including restoration of at least 15% of degraded ecosystems, prioritizing the most degraded biomes, hydrographic regions and ecoregions, thereby contributing to climate change mitigation and adaptation and to combatting desertification.

According to the NBSAP (Brazilian Ministry of Environment, 2017a), fifty-six actions were defined to fulfil this target, eleven were focused on the recovery of 15% of degraded ecosystem areas, thirty-six are related with conservation measures and eight support both conservation and restoration.

Despite the target of 15% forest/ecosystem restoration, no base reference, in absolute terms, is set to calculate the total area that should be restored yet. In fact, according to Action 10, the identification of the priority areas for restoration will be finished by 2018, just two years before the deadline. Accordingly, it is not possible to determine with precision the area interested by the reforestation under the NBSAP.

Finally, NBSAP does not provide information regarding the investments required for the reforestation measures nor the equivalent GHG emissions abatement. It is worth mentioning that, like the Brazilian NDCs (Federative Republic of Brazil, 2015), NBSAP also supports the implementation of the New Forest Code.

2.2.3 New Forest Code

The Native Vegetation Protection Law (aka New Forest Code) was approved in 2012, after years of extensive political work with the farmers, environmentalists, policy makers, politicians and civil society (Federative Republic of Brazil, 2012).

This law sets new directives for protection, exploitation and restoration of the native vegetation, as well as identifies the role and the level of responsibility of each stakeholder (e.g., public sector, land owners, agribusiness companies). It also defines new instruments regarding rural land registry, native vegetation monitoring and environmental adequacy.

One of the key points of this law is the delimitation of mandatory native vegetation areas inside private rural properties, labeled as Permanent Preservation Area (APP) and Legal Reserve (RL).

APP is a natural vegetation protected area with the environmental function of protecting the water resources, landscape, soil, geological stabilizations and biodiversity (Federative Republic of Brazil, 2012). Apart from rare exceptions or previous authorization, this area should be consisted of only native vegetation. Economic and/or productive activities are prohibited.

RL is a vegetation area, inside a rural property, with the function of supporting conservation and of ecological processes and biodiversity, as well as ensuring the sustainable use of property's natural resources for economic purposes (Federative Republic of Brazil, 2012). Differently from the APP, RL vegetation can be consisted of a maximum 50% of exotic species and it can be economically exploited by means of sustainable forest management techniques (SFM)[4].

Another important topic addressed by this law is the implementation of the Rural Environmental Registry – CAR (Federative Republic of Brazil, 2012). It consists of georeferenced identification of all Brazilian rural properties, delimited by APP, RL, native vegetation remains, consolidated rural areas and public interest areas.

According to the Brazilian Government (Federative Republic of Brazil, 2018), all rural areas should be registered under CAR system by 31st December 2018. After this date, the farmer whose land is not registered lose access to rural credit lines and other benefits (Federative Republic of Brazil, 2012).

This deadline should be sufficient to conclude the fully registration of all regions. By July 2018, just Mid-West and Northeast regions didn't finished the registry procedure, however they were not far from it: Mid-West registered 98.8% of its rural area and Northeast achieved 99.1% (Brazilian Ministry of Environment, 2018a). After the CAR's full implementation and validation, it will be known which properties have environmental debts and how they can procced to normalize this situation.

It is estimated that roughly 53% of Brazilian native vegetation are located on private properties and the full implementation of the Forest Code would represent the recovery of 21±1 million hectares between APP and RL (Soares-Filho et al., 2014). From this number, the Brazilian Ministry of Environment (2017c) defined minimum restoration target of 12 million hectares by 2030, as stated by National Policy for Recuperation of Native Vegetation – PROVEG (Federative Republic of Brazil, 2017a) and the National Plan for the Recuperation of Native Vegetation – PLANAVEG (Brazilian Ministry of Environment, 2017b, 2014).

Despite the targets from the PROVEG and PLANAVEG being analogue to the Brazilian NDC forestation target, the role of reforestation activities is not considered. They are under the responsibility of the Brazilian Ministry of Agriculture, as defined by the Agriculture Policy Law (Federative Republic of Brazil, 1991) and reaffirmed by the National Agricultural Policy on Forestry (Federative Republic of Brazil, 2014).

2.2.4 National Agricultural Policy on Forests

Brazilian planted tree industry is a key sector for country's economy. Covering 7.8 million hectares, mostly by Eucalyptus and Pinus monocultures, it is responsible for 91% of all wood produced for industrial purposes in the country, which encompasses pulp, paper, wood panels, laminate flooring, charcoal, and biomass (IBÁ, 2017).

From a production perspective, Brazilian planted forests have the highest productivity (measured as the volume of wood produced per unit area per year) and the shortest rotation (period between planting and harvesting of trees) in the world (IBÁ, 2017). Still, in order to attend to the growing domestic and international demand for forest products, the area of planted forest should increase.

To this end, Brazilian Government launched the National Agricultural Policy on Forestry (Federative Republic of Brazil, 2014). The policy aims to increase the production and the productivity from the planted forests, whilst reducing the pressure over native forests for forest products and services. It also set the development of a 10-year National Plan for the Development of Planted Forests - PNDF, which should contain the current situation from the planted forest sector, future scenarios which consider international and macroeconomy tendencies, and forestry production targets.

A preliminary version of PNDF (Brazilian Ministry of Agriculture Livestock and Food Supply, 2017) suggests the increase of the planted forest area from the current 7.8 million hectares to 10.6 hectares by 2025, an increase of 2.8 million hectares. World Bank (2017) points out that to attend to the growing demand for forest products, the increase of area could achieve 7 million hectares[5], more than the half of the NDC forestation pledge.

Finally, Table 2.1 presents a summary of the current forestation commitments, policies and plans (including the NDC) with respect to target area and deadline:

Table 2.1 Target areas and deadlines from Brazilian forestation pledges, policies and/or plans.

Pledge/Policy/Plan	Target Area	Deadline
Nationally Appropriate Mitigation Actions and PNMC	**3 Mha** All reforestation	2020
Nationally Biodiversity Targets and NBSAP	Restoration of 15% of degraded ecosystems	2020
New Forest Code, PROVEG and PLANAVEG	**12 Mha** All forest restoration	2030
National Agricultural Policy on Forests*	**2.8 Mha** All reforestation	2025
Nationally Determined Contributions	**12 Mha** Forest restoration and/or reforestation	2030

* Preliminary version. Source: Brazilian Ministry of Agriculture Livestock and Food Supply (2017).

2.3 Pathways to achieve Brazilian NDC for forestation

New Forest Code and PNDF set the domestic framework to implement both forest restoration and reforestation measures towards the fulfilment of Brazilian NDC target for forestation. Still, the lack of a sub-target for each of these forestation activities leads to uncertainties regarding which one should be prioritized and how.

The first study evaluated is the National Plan for Recuperation of Native Vegetation – PLANAVEG, developed by the Brazilian Ministry of Environment (2017b, 2014). Although it was initially created for the implementation of the New Forest Code and the PROVEG, PLANAVEG has a recognized relevance in addressing forest-related NDCs, as well as complying with the NBSAP (Brazilian Ministry of Environment, 2017b).

As presented in Section 2.2.3 and Table 2.1, also PLANAVEG sets a target of 12 million hectares of new forests by 2030, but, differently from the NDC, this should be pursued only by forest restoration. The plan assumes that the recovery rate of native vegetation increases over time, as the structural conditions for large-scale recovery are implemented. Accordingly, the forest recovery pathway takes a geometric progression, starting with 50 thousand hectares (recovered area in the first year - 2017), achieving about 534,319 hectares at the 5th year and finally 12.5 million hectares by 2030, which is 500 thousand more hectares than the original target of 12 million hectares (Figure 2.1).

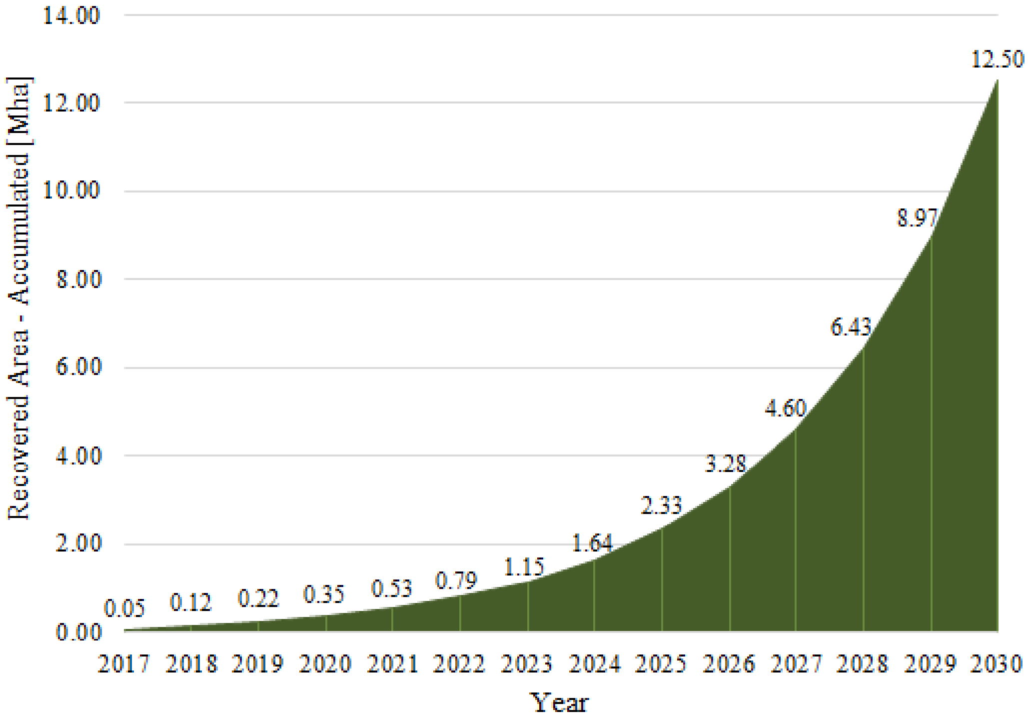

Figure 2.1 PLANAVEG’s projection for accumulated recovered area.
Source: Elaborated by the author, based on Brazilian Ministry of Environment (2017b).

An alternative study was developed by Instituto Escolhas (Kishinami et al., 2016) that considers the recuperation of 12 million hectares of RL, using both native and exotic tree species, with the possibility of economic usage by means of SFM.

It follows the preliminary version of PLANAVEG (Brazilian Ministry of Environment, 2014), and proposes a geometric progression of the recovered areas, starting from 136 thousand hectares by the end of 2015 (beginning of 2016) and an end point of 12 million hectares by 2030, same as NDC target for forestation (Figure 2.2).

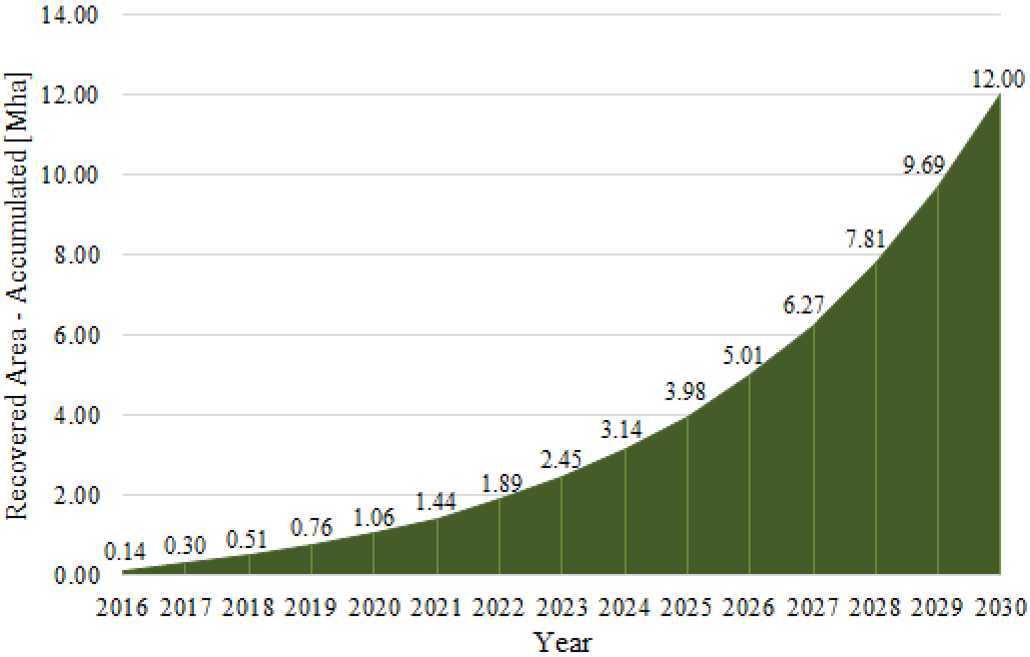

Figure 2.2 Projection for accumulated recovered area from Instituto Escolhas.
Source: Elaborated by the author, based on Kishinami et al. (2016).

The third study is from the World Bank (2017). This work sustains that the 12 million hectares target is laudable, but it could be even more ambitious. For this reason, it evaluates two different recovery targets, one of 12 million hectares of forest restoration by 2030 (coinciding with PLANAVEG's prescriptions), and other of 20 million hectares (estimated area required to be in full compliance with the New Forest Code).

In the present study, just the 12 million hectares goal is considered, as it represents the current NDC target for forestation. Two different recovery pathways for the achievement of the goal are developed, one based on a linear progression with constant growth rate of 0.8 Mha/year (Figure 2.3) and the other with increasing growth rate until the fifth year, and constant rate of 1 Mha/year afterwards (Figure 2.4).

The fourth study is the research conducted by the Brazilian Ministry of Science, Technology, Innovation and Communication (MCTIC), in partnership with United Nations Environment division (Rathman, 2017; Rathman et al., 2017). This work defines a list of cost-effective sectorial mitigation measures that would be necessary to fulfil Brazilian emission targets (1,300 $MtCO_{2eq}$ emission by 2025 and 1,200 $MtCO_{2eq}$ emission by 2030).

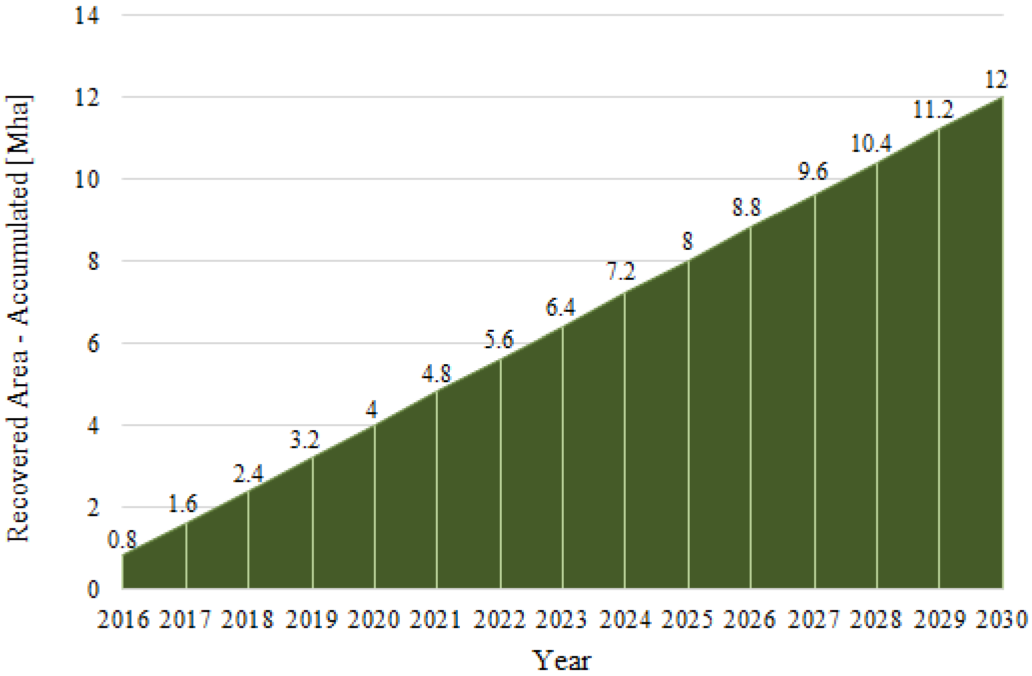

Figure 2.3 Accumulated recovered area considering constant growth rate.
Source: Elaborated by the author, based on World Bank (2017).

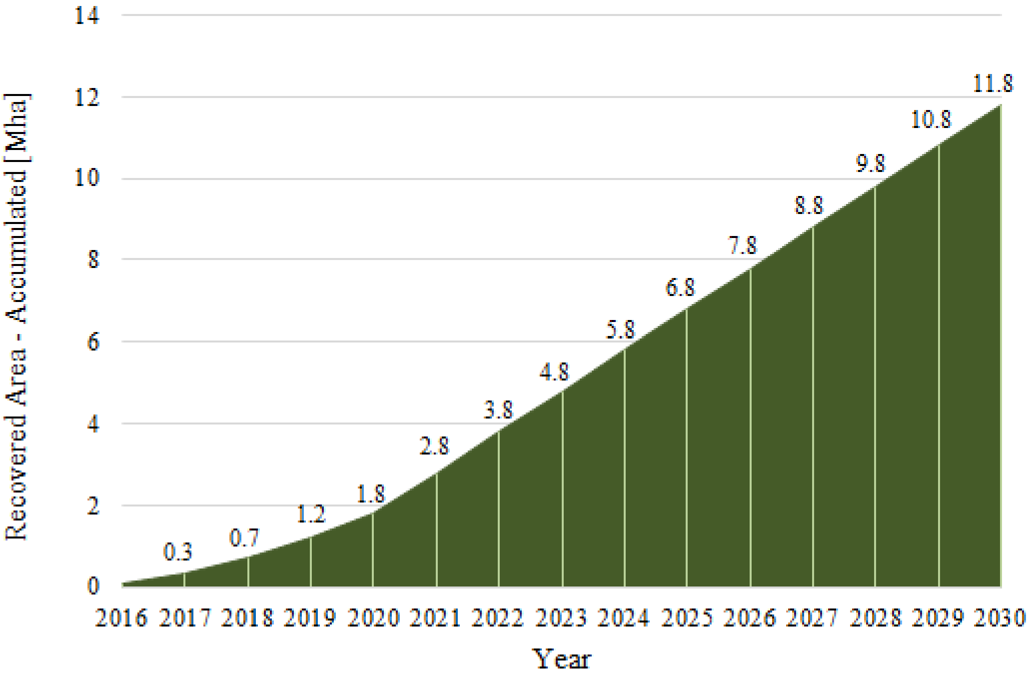

Figure 2.4 Accumulated recovered area considering a slow start in the first 5 years.
Source: Elaborated by the author, based on World Bank (2017).

Economic models were used to test different scenarios to identify the best cost-effective measures, considering economic growth, populational growth, resources competition among sectors (including land competition) and carbon taxation. The expansion of planted forests was framed to fulfil the growing need for forest products, while forest recovery was modelled to achieve 21 million hectares of area expansion by 2050. Rather than projecting a yearly forestation pathway, MCTIC sets milestones to be achieved by 2025 and 2030 (Table 2.2).

Table 2.2 MCTIC forest expansion targets by 2025 and 2030[6]. Source: Rathman (2017).

Forestation Technique	Year	
	2025	2030
Forest Recuperation [Mha]	6.1	8.4
Reforestation [Mha]	1.4	2.6
Total [Mha]	7.5	11

The study suggests an expansion of 2.6 million hectares of forest plantations to meet the increasing demand for forest products and another 8.4 million hectares of forest recuperation by 2030, resulting in 11 million hectares of new forests (91.7% of NDC target). By not explicitly setting the economic models to achieve 12 million hectares of forest expansion in 2030, the study's results diverge from the original NDC target.

2.3.1 Implementation costs

Forest recovery costs can vary greatly depending of the type of biome, geographic position, level of land degradation and restoration technique. Since the data about the distribution of the degraded area and its respective level of degradation is still partially unknown, different assumptions and scenarios were considered.

PLANAVEG defined three different scenarios, i.e., A, B and C, according to the different mixes of restoration technique suggested. These are: total planting (very high level of land degradation), high enrichment and high density (high level of land degradation), low enrichment and low density (medium level of land degradation), natural regeneration - with enclosure (low level of degradation, maintenance against exotic species required), and natural regeneration - abandoned pasture (low level of degradation, no maintenance required).

Scenario A prioritizes total planning over the other techniques while scenario C prioritizes natural regulation (with enclosure and abandoned pasture) over the others. Scenario B, in turn, appears as middle-term scenario, presenting a more balanced distribution among techniques. Table 2.3 introduces these three scenarios, as well as their average cost per hectare. Scenarios with higher share of total planting presented the higher costs, as this technique is significantly more expensive than the others. The aggregated costs varied from \$1,065.20[2] to \$1,572.73[2], which indicates that, until 2030, recovering 12 million hectares of forests may cost from 12.8 to 18.9 billion dollars.

Table 2.3 PLANAVEG's recuperation scenarios.

Restoration Approach	Description	Cost[2]	Scenario		
		[USD/ha]	A	B	C
Total Planting	1.666 seedlings / ha	$3,132.93	30%	20%	10%
High enrichment and high density	800 seedlings / ha	$1,566.47	15%	15%	15%
Low enrichment and low density	400 seedlings / ha	$1,065.20	15%	15%	15%
Natural regeneration (with enclosure)	Enclosure and control of *Brachiaria spp.*	$751.90	20%	25%	30%
Natural regeneration (abandoned pasture)	Abandoned areas (low agricultural productivity or capacity)	$438.61	20%	25%	30%
	Average Costs [USD/ha]		**$1,572.73**	**$1,318.96**	**$1,065.20**
	Total Costs [MM USD]		**18,872.76**	**15,827.52**	**12,782.40**

Instituto Escolhas improved the analysis defining six different scenarios, considering the share of each biome at the total target (Amazon Forest and Atlantic Forest – other biomes were left out) alongside the share of the restoration techniques.

The share of each biome was defined using the data provided by the Brazilian Agricultural Census (Brazilian Institute of Geography and Statistics, 2006) and the study performed by Soares-Filho (2013). From the Census data, it was estimated that the 24.2% of the 12 Mha target (2.9 Mha) would be consisted of Atlantic Forest and the other 75.8% of Amazon Forest (9.1 Mha). From Soares-Filho's study, the shares were 37.5% to Atlantic Forest (4.5 Mha) and 62.5% to Amazon Forest (7.5 Mha).

The restoration techniques shares were the same proposed by PLANAVEG (scenarios A, B, and C from Table 2.3). In addition to the implementation costs, the potential economic incomes from timber extraction under a SFM regime were estimated for all scenarios, as a funding mechanism (Table 2.4).

Table 2.4 Instituto Escolhas' scenarios. Adapted from: Kishinami et al. (2016)

Scenario	Costs per Area[2] [USD/ha]	Income per Area[2] [USD/ha]	Net Costs per Area[2] [USD/ha]
Census + PLANAVEG A	$1,353.15	$602.36	**$750.79**
Census + PLANAVEG B	$1,085.15	$466.62	**$618.53**
Census + PLANAVEG C	$817.19	$330.89	**$486.30**
Soares-Filho + PLANAVEG A	$1,325.26	$600.91	**$724.35**
Soares-Filho + PLANAVEG B	$1,076.50	$465.45	**$611.05**
Soares-Filho + PLANAVEG C	$810.70	$329.99	**$480.71**

Likewise PLANAVEG, scenarios with higher share of total planting (A and B) presented the higher costs. Scenarios with higher shares of Amazon Forest (Census) presented marginal higher costs. Gross costs varied from $810.70[2] to $1,353.15[2] per hectare, or from 9.7 to 16.2 billion dollars for 12 million hectares.

These costs decrease about 43% when the incomes from SFM are considered, achieving net values from $480.71[2] to $750.79[2] per hectare, or from 5.7 to 9 billion dollars for 12 million hectares. Instituto Escolhas also presented a list of forest products, other than timber, that could complement SFM incomes, such as native fruits and nuts.

In addition to accounting for SFM incomes, Instituto Escolhas also performed a sensitivity analysis for scenario “Soares-Filho + PLANAVEG A”, varying different cost criteria (e.g., implementation costs, tax regime, labor market). Reducing land fencing and choosing real profit over presumed profit as the basis for tax calculation were the best measures to reduce expenses. In a period of 35 years, the first accounted for a 24% cost reduction, while the second accounted for 10%.

World Bank calculations were based on the share of forest recovery technique required for each Brazilian biome. They used the data provided by PLANAVEG (Brazilian Ministry of Environment, 2017b, 2014) and Instituto Escolhas (Kishinami et al., 2016) to define the share and the costs of each technique considered. The results are presented in Table 2.5 showing that the biomes with higher recuperation costs are the ones with higher share of total planting (Atlantic Forest and Caatinga).

Table 2.5 World bank recuperation costs estimates by biome. Source: World Bank (2017).

Biome	Recuperation Method						Average cost per area [USD/ha]
	Total Planting		High Enrichment		Natural Regeneration		
	Share [%]	Cost per area [USD/ha]	Share [%]	Cost per area [USD/ha]	Share [%]	Cost per area [USD/ha]	
Pampa	28.3%	$2,570.00	44.7%	$1,013.00	27.0%	$400.00	$1,288.12
Pantanal	19.1%	$2,570.00	18.0%	$1,013.00	62.9%	$400.00	$924.81
Caatinga	53.3%	$2,570.00	0.0%	$1,013.00	46.7%	$400.00	$1,556.61
Atlantic Forest	46.0%	$2,570.00	47.8%	$1,013.00	6.2%	$400.00	$1,691.21
Cerrado	22.3%	$2,570.00	46.6%	$1,013.00	31.1%	$400.00	$1,169.57
Amazon	2.8%	$2,570.00	22.4%	$1,013.00	74.8%	$400.00	$598.07

From biome average and the estimated area to be recovered, it was possible to calculate the total costs (Table 2.6). Regardless of the adopted forest area growth rate, the estimated costs were about 13.7 billion dollars, within the cost ranges found by PLANAVEG and Instituto Escolhas.

Table 2.6 World bank total costs estimates. Source: World Bank (2017).

Biome	Area [1000 ha]	Total Cost [1,000 USD]
Pampa	356	458.6
Pantanal	76	70.3
Caatinga	694	1,080.3
Atlantic Forest	3,486	5,895.6
Cerrado	3,064	3,583.6
Amazon	4,311	2,578.3
Total	**11,987**	**13,666.7**

Finally, MCTIC collected the costs for employment and 2-years maintenance of different forest recuperation techniques (Total planting, partial Planting, high enrichment, low enrichment and natural regeneration) to estimate the total costs to recover 8.4 Mha of forests by 2030.

For APP, it was considered the use of natural regeneration due the higher probability of the existence of seed banks and forest fragments on the surroundings. For RL areas, all techniques were considered, depending to their proximity with other forest fragments. In cases where the area to be recovered were too far from other forest fragments (more than 1 km) and had low favorability for natural regeneration, partial planting was prioritized rather than total planting due its lower costs.

The results suggest the need of 9.9 billion dollars[2] until 2030 to restore 8.4 million hectares by 2030. In regard to the expansion of 2.6 million hectares of planted forests, the costs for implementation were around \$2,057.16[2] per hectare (without considering the harvesting), which would represent a total investment of 5.3 billion dollars until 2030. Though, it is important to point out that, differently from the recuperated forests, forest plantations can be a very lucrative business (IBÁ, 2017) and, thus, these investments have higher possibilities to be recovered in the middle-term.

2.3.2 Mitigation potential

Mitigation potential estimations also differ across studies. PLANAVEG used the data provided by Soares-Filho (2013), which calculated that recovering 21 million hectares of native forests has the potential to withdraw 1 billion ton of carbon from atmosphere in 20 years.

Using the same ratio for carbon sequestration potential per area, it was possible to presume that, in 20 years, restoring 12 million hectares of forests would sequestrate 0.6 billion ton of carbon (~2.1 $GtCO_{2eq}$[7]) from the atmosphere.

Instituto Escolhas estimated the mitigation potential by modelling the yearly biomass growth of each tree multiplied by the number of trees necessary to implement its pathway. The calculations considered just the tree aboveground biomass, ignoring roots and tree litter. According to Kishinami et al. (2016), the restoring 12 million hectares of forests would allow the absorption of 3.2 $GtCO_{2eq}$ by 2030.

World Bank calculated the mitigation potential by considering the amount of carbon contained in area of recovered forest equal to the carbon contained in a partial degraded area from a grown forest. A ratio of 0.78 was used for all biomes, replicating the ratio found by Poorter et al. (2016) for the Atlantic Forest biome. Using this approach, World Bank report estimated that the climate change mitigation benefits associated with the Brazilian restoration target would be 1.4 $GtCO_{2eq}$ (World Bank, 2017).

MCTIC estimated that the expansion of 8.4 million hectares of native forests by 2030 would sequestrate from atmosphere about 0.6 $GtCO_{2eq}$, as the yearly carbon absorption capacity from the recovered areas will be relatively low during the first years.

For the expansion of planted forests, on the other hand, the estimations were calculated considering highly productive tree plantations (i.e., Eucalyptus and Pinus), with an average absorption capacity of 60 $MtCO_{2eq}$ per year for the period 2020-2030. Summing up, the mitigation potential from the planted forests would add 0.6 $GtCO_{2eq}$ to the total mitigation potential, resulting in a total mitigation potential of 1.2 $GtCO_{2eq}$.

2.3.3 Financial support

All studies recognized the importance of financial support for the fulfilment of the forestation target, particularly for the promotion of forest recuperation and suggest different strategies to increase the effectiveness of existing funding mechanisms and possibly expand them.

PLANAVEG performed the more extensive analysis and recommended, a portfolio of financial tools and mechanisms to promote the recuperation of forests. The plan recognizes the existence of some dedicated credit lines for forest restoration, but it ascertains that they are poorly promoted, have some entry barriers for small landholders or, for RL areas, present grace periods and instalments which are not in line with the cash flow required for with the sustainable management of the recovered areas.

Thus, PLANAVEG proposes the improvement of some existing credit programs, such as the Low-Carbon Agriculture Program (ABC) and the National Program for Strengthening of the Family Agriculture (PRONAF), to fit better to the requirements for a forest recovery projects. It also suggests the development and use of long-term financial tools, such as forest bonds and/or debentures, and the implementation of tax exemptions for products and activities associated with forest restoration.

To complement the forest financing portfolio, it encourages the use of non-repayable funds[8] (e.g., funds provided by the National Fund for Environment – FNMA) and the conversion of environmental fees to support forest recovery projects. PLANAVEG however didn't present any estimates about how and how much each financing source would contribute to the more than the $ 12 billion required for the program.

Instituto Escolhas just replicated the existing lines of credits mapped by Forestry Funding Guide - developed by the Brazilian Forestry Service (2016) - with no further suggestions about improvements or new mechanisms.

World Bank highlighted that the rural credit programs will be key to unleash the massive forest restoration. However, improvements in accessing these programs are required specially to tackle the main barriers to credit taking: low supply of qualified technicians for the development of forestry projects, high initial investment/cost, and low liquidity from restoration activities when compared with other agricultural ones.

It recommends the restructuring of the available public credit lines by increasing their credit limits and dissemination, to achieve the necessary scale and to match with the environmental and social impacts expected by the government. In addition, it suggests the expansion of payment for ecosystem services schemes as a way for backing the costs of implementation.

As complementary measures, it suggested to make use of national/international funds that can be relevant for restoration in Brazil (e.g., Global Environmental Facility and Green Climate Fund) and pointed out the potential of creating tradable climate bonds.

MCTIC recognized that there are few incentives for forest recuperation and, for this reason, new economic instruments should be introduced, alongside with subsided credit lines. Besides that, the concession of commercial (e.g., access to markets) and fiscal benefits (e.g., tax exemption/reduction) to those in compliance with the recuperation of APP and RL would also be relevant incentives.

In regard to reforestation, it highlights the promotion of minimum prices for forest products, the sharing of the risks between producers and purchasers, and more attractive credit lines, with better interest rates and grace periods.

Table 2.7 synthetizes their main points, considering the forestation target area, implementation pathway, costs, mitigation potential and financial support.

Table 2.7 Approaches' key points.

Approach	Target Area	Pathway	Total Costs [Billion USD]	Mitigation Potential [$GtCO_{2eq}$]	Financial Support Recommendations
PLANAVEG	**12 Mha** All forest restoration	**Shape:** Geometric Progression **Milestones** **2017:** 0.05 Mha **2021:** 0.53 Mha **2030:** 12.00 Mha	12.8 - 18.9	2.1	• Improvement and/or introduction of subsided credit lines; • Tax benefits; • Development of climate/forest bonds; • Development of forest debentures; • Conversion of environmental fees.
Instituto Escolhas	**12 Mha** All forest restoration	**Shape:** Geometric Progression **Milestones** **2016:** 0.14 Mha **2030:** 12.00 Mha	**w/ SFM** 5.7 - 9 **w/o SFM:** 9.7 - 16.2	3.2	• **No improvement suggestions.**
Word Bank	**12 Mha** All forest restoration	**Shape:** Linear Progression **Milestones** Constant Growth **2016:** 0.80 Mha **2030:** 12.00 Mha Slow Start **2016:** - **2020:** 1.80 Mha **2030:** 12.00 Mha	13.7	1.4	• Improvement and/or introduction of subsided credit lines; • Development of climate/forest bonds • Expansion of payment for ecosystem services schemes; • Use of national/international funds for forest restoration.
MCTIC	**11 Mha** Forest Restoration 8.4 Mha Reforestation 2.6 Mha	**Shape:** Not Defined **Milestones** **2025:** Forest Restoration: 6.10 Mha Reforestation: 1.40 Mha **2030:** Forest Restoration: 8.40 Mha Reforestation: 2.60 Mha	15.2	1.2	• Improvement and/or introduction of subsided credit lines; • Tax benefits; • Commercial benefits.

2.4 Discussion

All the examined studies improved the understanding of complexities and challenges associated to Brazilian forest policies. Their scrutiny enables to identify the weaknesses of previous international commitments, i.e., NAMA's and the 20 National Biodiversity Targets, and their respective action plans, i.e., National Plan on Climate Change and NBSAP. The main lessons are the following.

Firstly, and perhaps trivially, it is fundamental to set with the highest precision possible, the forest area from which the forest expansion will be calculated. This was one of the problems found in the NBSAP for the 15th National Biodiversity Target, which pledged a relative target of restoring 15% of the degraded ecosystems, with no clear indication of how much area it would represent (see Section 2.2.2). This obviously makes any proper monitoring and evaluation of the fulfilment of the commitment difficult, if not impossible in practice. To this end, the conclusion of the registration and analysis of all rural areas at CAR is a necessary step to establish a robust and reliable initial ground for the process.

It is an important step to guarantee access to data with high level of confidence about total the situation of forests and degraded lands in rural properties. As indicated in Section 2.2.3, the registration of rural areas will most likely be finished by the end of 2018, this leaves just one year (i.e., 2019) for the registration analysis before the starting of the Paris Agreement (2020). Along this line, it is also crucial the splitting the 12 million hectares target in two sub-targets, one for reforestation and other for forest restoration. As recently advocated by the Brazilian Ministry of Environment (2017a), this definition is key to eliminate doubts about the global target, clearing the scenario for the design of the specific pathways and action plans for each forestation technique.

Another obvious mistake that should be avoided is to conclude the action plan after the beginning of their implementation period. Obvious it may seem, most PNMC's sectorial plans and the NBSAP were released after the starting period (2010-2020 for all cases), leaving little time to their effective implementation. Accordingly, some important measures should be settled before Paris Agreement starting period. In this vein, it is vital to conclude or update all sector plans (e.g., PNDF, PLANAVEG, ABC, sectorial plan for deforestation and steel industry), with a comprehensive communication/coordination effort by the government among its different ministries. This would avoid overlapping among public policies and programs regarding targets, responsibilities, resource allocation and implementation strategies.

Then, based on the new sectorial plans, it would be necessary to update the PNMC to upgrade the legal frame for the NDCs and release a new version of the National Plan on Climate Change for the period 2020-2030, containing the pathways and action plans for all sectors.

More in general, the reforestation and forest restoration pathways should be planned according to their respective realities. Planted forest sector is well developed and its expansion should be connected with the increasing demand for forest products, particularly pulp, timber, firewood and coal. In this sense, the conclusion of the PNDF is important to set premises and the framework for the design of the expansion pathway. The recuperation of forests, on the other hand, should first set the structural conditions and then push for large-scale implementation, in line with the geometric progression pathway sustained by PLANAVEG and Instituto Escolhas.

Defining sub-targets and pathways for forest recovery and reforestation should be the first steps before assessing mitigation potential and the implementation costs of NDCs' forestation target.

2.4.1 Mitigation potential and implementation costs

Mitigation potential results widely varied among the studies, as different approaches combined with different targets, time lengths and types of forestation were considered.

In view of the high levels of uncertainty mostly generated by the lack of information about the degradation level of the areas to be recovered, the choice for more conservative methods for estimation, such as the one used by MCTIC, seems more reasonable for a preliminary evaluation of the situation, avoiding, thereby, overcounting the mitigation potential.

Regarding the implementation costs, the estimates varied from 9.7 to 18.9 billion dollars (until 2030), in accordance with the level of land degradation and the consequent mix of planting techniques considered by each study (see Section 2.3.1).

Among all forest recovery techniques, natural regeneration is the least complex planting method and its costs are just a fraction of the others. The promotion of this technique over the others is the natural way to consistently reduce the costs and the difficulty of implementation. To this end, reliable information about the location and the status of the degraded areas are essential to minimize implementation costs without compromising the success of forest restoration.

Still, as noticed by World Bank (2017), there is little intelligence about the real situation of the degraded areas, their level of degradation and spatial distribution, which makes problematic to judge the full applicability of this low-cost technique. Thus, beyond the reduction in costs in absolute terms, World Bank (2017) stresses that identifying areas with high potential for natural regeneration could greatly decrease the uncertainty involving the calculations for forest recuperation costs.

Apart from that, all works point out the importance on the development of production and distribution networks for native seeds, seedlings and other relevant materials (e.g., supplies for fencing) to unlock the large-scale implementation of the other planting techniques, which, as an indirect result from the scale effect, would also decrease their implementation costs.

After the efforts for decreasing the absolute value and the uncertainties regarding the magnitude of the implementation costs, it would be possible to develop more effective mechanisms to provide financial support for them.

2.4.2 Financial mechanisms to support forestation projects

The importance of public credit lines for supporting the expansion of 12 million hectares of forests all around the country is a common ground and some mechanisms are already available for this purpose.

According to the Forestry Funding Guide (Brazilian Forestry Service, 2016), there are some credit lines focused on reforestation and forest recuperation within the ABC and PRONAF programs (see Section 2.3.2), the National Program to Support the Medium Rural Producer (PRONAMP), the Brazilian Development Bank (BNDES), as well as the National Fund for Environment – FNMA (Brazilian Ministry of Environment, 2018b).

Although the information about granted credit are public and freely available at the internet (Brazilian Development Bank, 2018; Brazilian Ministry of Environment, 2018b; Central Bank of Brazil, 2018a), it is difficult to calculate the real magnitude of these loans. The main reason is because both forest restoration and reforestation activities are often financed along with other productive activities, without clear distinctions among different credit lines (Brazilian Development Bank, 2018; Central Bank of Brazil, 2018a; Costa, 2016; Monzoni and Vendramini, 2017).

From 2015 until 2017, the loans granted for reforestation activities were about 1.1 billion of dollars[2] (~375 million dollars per year), all from repayable funds[9] (i.e., ABC, PRONAF, PRONAMP and BNDES - Brazilian Development Bank, 2018; Central Bank of Brazil, 2018b).

Considering the low level of area expansion during this period (around 111 thousand hectares in 3 years - IBÁ, 2017, 2018) and the specifications provided by the credit providers (Brazilian Development Bank, 2018; Central Bank of Brazil, 2018a), it is possible to infer that almost all the loans were intended to productive and maintenance activities of existing tree plantations rather than their expansion.

With respect to forest restoration activities, Table 2.8 presents the aggregated financing data for the period, gathered from the Brazilian Matrix for Rural Credit (containing ABC, PRONAF and PRONAMP programs - Central Bank of Brazil, 2018b), BNDES (2018) and FNMA (Brazilian Ministry of Environment, 2018b).

Table 2.8 Granted credit for forest recovery, from 2015 to 2017, in USD[2].

Type of Credit	**Year**			**TOTAL Credit per Type**
	2015	**2016**	**2017**	
Repayable	$116,085,643.66	$44,725,830.03	$41,908,277.25	**$202,719,750.94**
Non-Repayable	-	$4,587,728.54	$7,046,792.17	**$11,634,520.71**
TOTAL Credit per Year	**$116,085,643.66**	**$49,313,558.57**	**$48,955,069.42**	**$214,354,271.65**
			AVERAGE Credit Per Year	**$71,451,423.88**

From the total amount of granted credit, 95% was provided by repayable credit (mainly from ABC program, which represented 60% of the total), and the other 5% come from non-repayable funds (provided by the FNMA and the Social Fund from BNDES).

Even when these aggregated values are considered, the total amount of granted loans intended to support forest recovery activities has been far away from the necessary. Extrapolating the average credit per year for the period 2020-2030 (2030 included), the total credit be around 0.8 billion dollars, just a small fraction from the estimated costs presented in Section 2.3.1 (from 9.7 to 18.9 billion dollars). There is then a further problem. Despite the existence of dedicated credit lines for forest restoration, lack of incentives and some entry barriers inhibit farmers from using the loans. As an example, at least US$ 1.4 billion was offered for the restoration of degraded land (including degraded pastures) in 2014, but less than 5% was taken (World Bank, 2017).

To address this barriers, PLANAVEG, World Bank and MCTIC advocate the reformulation of the existing credit lines by establishing more attractive grace periods, credit limits and interest rates, in line with the producers cash flow (Brazilian Ministry of Environment, 2017b; Rathman, 2017; World Bank, 2017). This measure is endorsed by Costa (2016) and Monzoni & Vendramini (2017), which also identify at the conclusion of CAR's implementation a great incentive to increase the demand for forest recovery loans, since the recovery of degraded forests/lands should start after CAR's fulfilment.

Monzoni & Vendramini (2017) further recommend providing restoration activities the access for instalment loan options, such as the ones available to support farmer's running costs. According to their results, farmer's capacity of payment is higher for type of loan than the currently available loan options (i.e., investment loans). It would also enable the phased implementation of forest recovery activities, distributing over time the potential loss of productive area.

All these measures would promote the adhesion from rural producers to forest recovery credit programs, increasing the demand for credit. However, this higher demand for financing can stumble upon the constitutional amendment nº 95 from 2016, which defines Brazilian new fiscal regime (Federative Republic of Brazil, 2016). According to this amendment, until 2036 (with a verification point in 2026), Brazil's public yearly budget can be only corrected by the official inflation, with no real gains in value.

It also certifies that, in case of exceeding the global public budget, federal government is forbidden to create or expand financing programs, credit lines, fiscal benefits and other forms of subsides. In other words, until 2036, the creation of new credit or subsidy is just possible by the allocation of resources from other areas of the federal budget.

Thus, beyond the credit enlargement, Brazilian new fiscal regime also has the potential to hinder the implementation of tax reduction to decrease the costs of forest restoration activities and other fiscal incentives proposed by PLANAVEG (Brazilian Ministry of Environment, 2017b) and MCTIC (Rathman, 2017).

In this scenario, the quest for different ways to provide financial support to fulfil Brazilian NDC for forestation other than increasing public credit/subsidy is required. An option that has been poorly explored in the last years is the conversion of environmental fees. According to the Brazilian Institute of the Environment and Renewable Natural Resources – IBAMA, 0.9 billion dollars[2] of environmental fees are issued every year, but just 5% of this amount has been in fact collected by the institute (Federative Republic of Brazil, 2017b).

To change this situation, in 2017, Brazilian government established a federal decree to facilitate the payment of environmental fines by creating two different compensation methods (Federative Republic of Brazil, 2017c). The first method consists of the promotion of environmental preservation, improvement and/or recuperation services by the debtor, using its own means. For those who subscribe for this method, it will be offered a 35% discount on the total debt amount.

The second method consists of the debtor's accession to an environment project previously selected by the environmental government body that issued the fee. In this case, a discount of

60% will be granted (Federative Republic of Brazil, 2017c). After this decree, Brazilian government expects to convert about 1.44 billion dollars[2] of existing environmental debts in the next few years (Federative Republic of Brazil, 2017b).

Another source of resources is the international community. Despite the implementation of Brazilian NDCs is not contingent upon international aid, it welcomes the support from developed countries with a view to generate global benefits (Federative Republic of Brazil, 2015). In this context, Brazilian Government released bilateral joint-statements with three different developed countries: Norway (Federative Republic of Brazil and Government of the Kingdom of Norway, 2015), Germany (Federal Republic of Germany and Federative Republic of Brazil, 2015) and United States (Federative Republic of Brazil and Federal Republic of United States of America, 2015).

All statements reinforce the importance of forests in the Brazilian mitigation strategy and define measures to improve deforestation prevention and forest restoration. While Brazil-Norway statement is concentrated on supporting deforestation reduction measures (Federative Republic of Brazil and Government of the Kingdom of Norway, 2015), Brazil-Germany one had defined a subsided credit line of 100 million euros (~113 million dollars[8]) to forest restoration activities, fully backed by German government (Federal Republic of Germany and Federative Republic of Brazil, 2015).

Brazil-US statement suggest the creation of a binational investment program, which would also count with private capital, to promote SFM and forest recovery (Federative Republic of Brazil and Federal Republic of United States of America, 2015). This initiative, however, has no further information of how and how much this investment program would contribute to the development of forest recuperation projects. In addition, the announcement of US withdrawn from Paris Agreement (BBC, 2017) puts the of joint-statement in doubt.

Nepstad et al. (2015) propose that the international support, provided by these bi-lateral agreements and multilateral development finance institutions (e.g., World Bank or the Green Climate Fund), should have a different role on backing Brazilian forestation target. According to them, rather than providing direct funding for forestation projects and programs, these agreements and finance institutions could support the development of Green Forest Bonds (GFBs), which has the potential to bring private capital to the equation and, thus, to drive the investments at the scale needed to achieve the forestation commitment.

These GFBs would be structured to provide investors the same return on investment and risk characteristics as normal “investment grade” bonds issued by governments. The international finance support would provide GFBs the safeguards required by investors for this type of investment, decreasing their risks and, consequently, their costs (i.e., interest rates).

The resources raised from GFBs would then capitalize forest restoration and reforestation credit lines, which would provide bond's interest remuneration by the payments from the loan takers. It is important to highlight that the long-term characteristic from forest recovery and reforestation projects perfectly matches with bond's duration, avoiding asynchronicity between loan takers payments and GFBs' compensation.

Capital market interest in green bonds has been growing globally. According to the Climate Bonds Initiative, the total issuance of climate bonds in 2017 was US$ 161 billion dollars and the projected amount for 2018 is around 250 billion dollars (Climate Bonds Initiative, 2018). According Green Climate Fund (2015), the use of bonds is particularly well suited to attracting funds at scale from commercial banks, pension funds, insurance companies, sovereign wealth funds and private wealth, which, in 2014, represented 217 trillion dollars in total assets.

Finally, considering its characteristics and the amount of resources it could potentially mobilize, GFB rises as the best solution to raise the resources needed to finance Brazilian NDC forestation target without compromising country's sensitive fiscal situation.

2.5 Conclusion and outlooks

The task to forest an area large as England is not simple, even for a country with the size of Brazil. The analysis of the works developed by PLANAVEG, Instituto Escolhas, World Bank and MCTIC contributed to understand the challenge involved, which can only be overcame by long-term efficient planning, concrete actions, support and coordination from all interested parts.

Among the different challenges, the present study highlights the following:

- The generality of the terms used to define the target, which creates ambiguity about which type of forestation should be prioritized (forest restoration or reforestation) and how to proceed with the target fulfilment;
- Little information about degraded areas situation, their level of degradation and spatial distribution, which hinders the development of action plans and costs estimates;
- Insufficient financial support to promote the investments required to forest 12 million hectares by 2030.

To address these issues, the following measures were proposed:

- Splitting the 12 million hectares target in two sub-targets, one for reforestation and other for forest restoration, clearing the scenario for the design of the specific pathways and action plans for each forestation technique;
- Mapping and characterization of degraded areas by means of CAR full implementation, setting the base ground for the commitment fulfilment and allowing the promotion of natural regeneration to reduce implementation costs;
- Establishment of more attractive grace periods, credit limits and interest rates for forest restoration credit lines in order to easy the access for the rural producers and to better attend their reality;
- Make use of environmental fees conversion to back, primarily, APP restoration projects;
- Creation of Green Forest Bonds backed by international support and devoted to jointly fund forest recovery and reforestation projects. These bonds would foster a reliable credit source for the long-term forestation projects while offering investors risks and interest rates equivalent to government bonds.

The action plans and activities involving the fulfilment of Brazilian NDC for forestation must be in line with the other NDCs. Future works could deeply address this issue, contributing to the development of a new Brazilian National Plan on Climate Changes. As suggested by World Bank (2017), further investigations of how and how much payment for ecosystem services programs could financially support forest restoration projects are also encouraged.

Finally, the full implementation of the forestation commitment is a great step towards a greener economy to the country, in which forests and their products will be increasingly integrated with markets, allowing the economic development and environmental conservation to shift from a competition to a symbiotic relation.

Notes

1. Instituto Escolhas is a Brazilian non-profit civil organization which aims to qualify the debate on sustainability by translating into numbers the economic, social, and environmental impacts of public and private decisions. Its produces data and materials (e.g., studies, analyses, and reports) to support new approaches and arguments capable of overcoming the ideological polarization in planning conflicting choices, enabling solutions to make sustainable development feasible (Instituto Escolhas, 2018);
2. Considering an exchange rate of 3.1919 BRL/USD, equals to 1-year average rate,

from 01/2017 to 12/2017 (Central Bank of Brazil, 2018a);

3. The authors considered the 2010 as the base year to verify the expansion, as it represents the year of the publication of the Decree for the National Policy on Climate Change, Nº 7.390, 9th December 2010, which set the 3 million hectares reforestation target;
4. Sustainable Forest Management – SFM is the management of the natural vegetation to obtain economic, social and environmental benefits, while respecting the maintenance mechanisms from the managed ecosystem and considering, cumulative or alternatively, the use of multiple timber and non-timber species, multiple products and sub products from native vegetation, as well the use of other goods and services (Federative Republic of Brazil, 2012);
5. According to the World Bank (2017), the National Agricultural Policy on Forestry aims to almost double the internal supply of forest products, by “doubling” the area of planted forests to reach an area of 14 million hectares. It assumes that, because Brazilian forest sector is highly efficient and the gains on productivity would be around 0.3% per year, the increase in production will largely come from area expansion;
6. Both reforestation and forest recuperation targets were defined considering low-carbon development scenario;
7. A ratio of 3.66 CO_{2eq}/C was used to convert carbon in carbon dioxide equivalent (Haynes, 2012);
8. Funds with no repayment requirements, such as outright grants;
9. Funds that must be repaid at a certain point in time and of which it is clear in advance the interest rate or/and nominal amount must be repaid to the funds’ provider;
10. Considering an exchange rate of 1.1301 USD/EUR, equals to 1-year average rate, from 01/2017 to 12/2017 (Federal Reserve, 2018).

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+20180227.xlsx?MOD=AJPERES&CACHEID=ROOTWORKSPACE.Z18_7QGCHA41LORVA0AHO1SIO51085-f14610e3-b3f9-41f8-92b5-f8ec02f41ca4-m7pb-P6

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3 BUSINESS SCENARIO ANALYSIS FOR NATIVE-EXOTIC MIXED FORESTRY PROJECT: A CASE STUDY FOR BRAZILIAN ATLANTIC FOREST

3.1 Introduction

Forestry can play a main role towards a more sustainable economy, providing renewable energy source, construction materials, fiber, other types of wood-based materials (Reid et al., 2004). In addition, planted forests can provide many of the ecosystem services associated with natural forests, such as erosion control, clean water production, regulation of hydrological cycle and carbon sequestration (Bauhus et al., 2010).

Land owners usually respond to economic risks and opportunities when allocating land to productive activities, such as agriculture, livestock or forestry. Among these options, forestry activities have a great potential for reliable future returns in many areas around the world, especially in Brazil. Cubbage et al. (2007) and Cubbage et al. (2010) found that the Internal Rate of Return (IRR) from *Eucalyptus* plantations in Brazil may vary from 21.4% to 25.5%. For Brazilian *Pinus* plantations, the IRR may vary from 16% to 20.8%.

According to the Brazilian Tree Industry (IBÁ, 2017), compared with other global players (e.g., China, EUA, Canada and South American countries excluding Brazil), Brazilian forestry sector has the best productivity results for both Eucalyptus (35.7 m^3/ha per year) and Pinus monocultures (30.5 m^3/ha per year). Together, these exotic species represent 92.47% (~7.25 million hectares) of all Brazilian planted forests (~7.84 million hectares).

Although these monocultures present outstanding productive and economical results, they also cause environmental drawbacks if compared with native forests, in special regarding biodiversity (Fonseca et al., 2009; Lindenmayer and Franklin, 2002), soil water availability (Amazonas et al., 2017) and tree life expectancy (Griess et al., 2012).

In this sense, the implementation of mixed-forest plantations arises as a more eco-efficient solution. Forest plantations using different types of trees, preferably native species, more closely mimic natural forests, which enhances many of the forest environmental services, sustain forest biodiversity and cause less negative environmental impacts (Davis et al., 2012; Pryde et al., 2015).

Keenan et al. (1999) defends that by mixing exotic and native species it is possible to achieve high productive tree plantations with greater environmental results. They point out that different species have different needs regarding water, soil nutrients and sunlight, which results in less competition among individuals, better use of the available resources, erosion avoidance and higher biomass productivity. Hartley (2002) presents similar findings from mixed plantations in his literature review paper.

Piotto et al. (2004) compared the productivity of fourteen tree species in Costa Rica (exotic and natives) and noted that native species grew better in mixed plots. They discuss that a possible reason is the diversity of species which contributes to a more balanced use of the site nutrients and access to sunlight. Finally, they point out that mixed plantations using native species contribute to a more sustainable management, increasing the range of forest good and services.

Amazonas et al. (2017) and Amazonas et al. (2018) investigated the trade-offs regarding the change from *Eucalyptus* monocultures to mixed native-*Eucalyptus* forest plantations. Their results indicate that, compared with Eucalyptus monocultures, mixed native-Eucalyptus tree plantations are technically feasible, has lower impact on soil water and account for an interesting alternative for establishing multipurpose plantations, particularly in the context of forest and landscape restoration.

Regarding the economic evaluation of native-exotic mixed forestry projects, few studies are available. Streed et al. (2006) performed an economic assessment for a small-scale mixed forestry project using 15 different species (exotic and natives). They collected data of project expenses, taxes and revenues in the first 15 years of the project and then estimated them for more 10 years to calculate the overall financial returns. Considering both collected and estimated data, the project presented an IRR of 7.37%. Piotto et al. (2010) compared the internal rate of return from sixteen native species in monoculture and mixed plantations plots. Their results show higher IRR values for mixed plots (from 7.71% to 15.64%) compared with single-species plots (from 2.85% to 14.29%). Both studies were conducted in Costa Rica.

The present paper aims to contribute to the available literature, providing a detailed economic analysis of a mixed exotic-native forestry case study situated in the Brazilian Atlantic Forest biome. Eight different business scenarios for the development of forest activity were proposed. They differentiate according to forest-based products (sawn wood and biomass for energy purposes), carbon credit accounting and target markets (local and external). Costs from forest plantation and management, as well as costs from forest-based products manufacturing and transportation were considered. The business scenarios were evaluated in terms of Net Present Value (NPV), Internal Rate of Return (IRR) and payback time. A sensitivity analysis tests the robustness of our results to changes in sawn wood and carbon credit prices.

3.2 Data and methods

3.2.1 Case study description

This analysis used the data from a reforestation project implemented by *Symbiosis Investimentos e Participações Ltda.,* a Brazilian forestry company. The project is sited at Porto Seguro/BA, a coastal city inserted at the Brazilian Atlantic rainforest biome, and aims to use a great variety of exotic and native tree species to produce sawn wood with high market-value. In addition to sawn wood, the residues from sawing process and the carbon credits generated from forest growth are also considered as possible incomes sources.

The project involves 150 hectares of productive area plus the recovery of 81 hectares of native forest for legal protection purposes (Federative Republic of Brazil, 2012). Prior to the reforestation, the area was composed by degraded pastures and coconut plantations. Twenty-six different species of trees were selected for planting, divided in accessory and main species.

For each hectare of the productive area, 1388 trees were planted: 555 of accessory species and 833 of main ones. Figure 3.1 illustrates the tree plantation scheme:

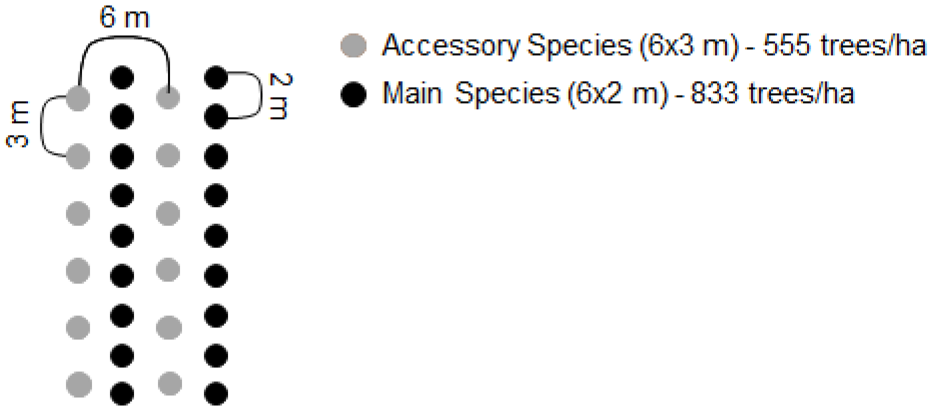

Figure 3.1 Forest plantation scheme.

Accessory species have a lower commercial value compared with the main ones, but they grow faster, providing the necessary shade to the development of the main species and the forest by itself. Due to their fast growth, they achieve maturity sooner and, therefore, have shorter harvest cycle if compared with main species, which have higher commercial value, lower growth rate and, consequently, an extended harvest cycle. Tables 3.1 and 3.2 introduce the selected accessory and main species respectively:

Table 3.1 Selected accessory species.

Accessory Species - 6 Species		
Scientific Name	**Common Name**	**Origin**
Khaya senegalensis	*African Mahogany*	*Exotic - Africa*
Melia azedarach	*Chinaberry*	*Exotic - Asia*
Eucalyptus cloeziana	*Gympie messmate*	*Exotic - Oceania*
Toona ciliata	*Australian Red Cedar, Toona*	*Exotic - Oceania*
Terminalia ivorensis	*Idigbo, Black Afara*	*Exotic - Africa*
Zeyheria tuberculosa	*Ipê Felpudo, Ipê Preto*	*Native - Brazil*

Table 3.2 Selected main species.

Main Species - 20 Species		
Scientific Name	**Common Name**	**Origin**
Plathymenia foliolosa	Vinhático	Native - Brazil
Anadenanthera peregrina	Angico Curtidor	Native - Brazil
Centrolobium robustum	Araribá robusto	Native - Brazil
Parapiptadenia pterosperma	Angico Vermelho	Native - Brazil
Schizolobium parahyba	Guapuruu	Native - Brazil
Cordia trichotoma	Afata, Louro-Pardo	Native - Brazil
Andira anthelmia	Angelim Amargoso, Angelim da baixada	Native - Brazil
Andira ormosioides	Angelim Pedra	Native - Brazil
Astronium fraxinifolium	Gibatão, Gonçalo Alves, Tigerwood	Native - Brazil
Astronium graveolens	Aderne, Gonçalo Alves, Tigerwood	Native - Brazil
Astronium concinnum	Gonçalo Alves, Tigerwood	Native - Brazil
Cariniana legalis	Jequitibá-Rosa	Native - Brazil
Handroanthus serratifolius	Yellow Ipê, Yellow Lapacho, Yellow Poui	Native - Brazil
Genipa americana	Jenipapo	Native - Brazil
Simarouba amara	Simarouba, Marupa, Caxeta	Native - Brazil
Bowdichia virgilioides	Sucupira, Sucupira-Preto	Native - Brazil
Dalbergia nigra	Brazilian Rosewood, Bahia Rosewood, Jacarandá-da-Bahia	Native - Brazil
Copaifera langsdorffii	Copaíba, Copaúva	Native - Brazil
Parkia pendula	Visgueiro, Juerana vermelha	Native - Brazil
Paratecoma peroba	Peroba do Campo, Peroba Amarela	Native - Brazil

The reforestation project is expected to last 48 years, which correspond to the total harvest cycle defined for the main species. Forestry implementation and management activities, and their costs, are provided by the Appendix A. Costs from land acquisition were not considered.

3.2.2 Growth estimation and harvest cycles

The growth estimation from both accessory and main species were performed applying individual tree growth models, which use the data collected from each specie to estimate the growth of each tree individually. This kind of model considers the different growth characteristics from the different species and is more suitable to estimate forests with great variety of tree species and with different harvest cycles, such as the one currently examined (Batista et al., 2014; Vanclay, 1994).

Rozendaal et al. (2015) used individual tree growth model to assess the height and the Diameter at Breast Height (or DBH) growth rates of three different tropical species from Bolivia, two of them shade-tolerant (similar to the main species) and the other one light demanding (similar to the accessory species). Therrell et al. (2007) also used the same type of model to estimate the DBH growth rate from *Pterocarpus angolensis*, a light demanding species originated from southern Africa. In both studies, the growth models presented linear behavior regarding their tree height and/or DBH estimates through the years.

Symbiosis collected information from more than 275,000 trees under 5 years old to feed the growth models with data regarding the DBH and height. The average estimates for tree DBH and height are presented by Figures 3.2 and 3.3, from both accessory and main species:

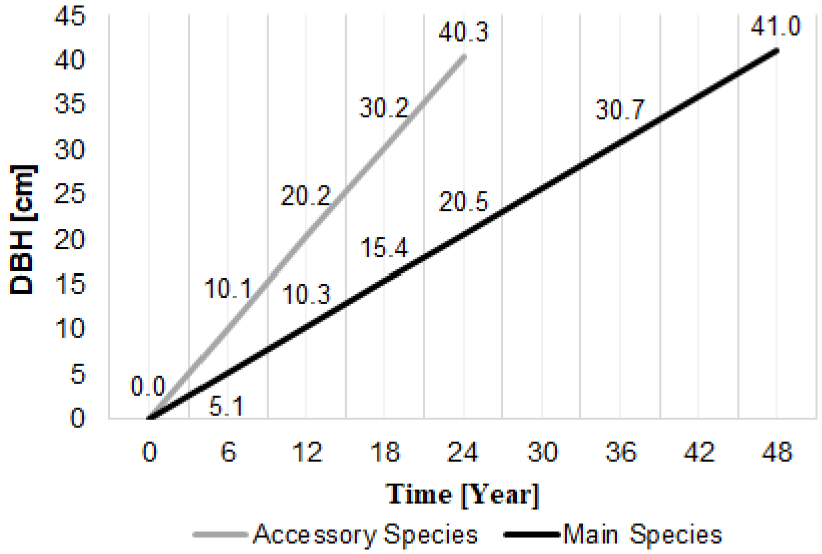

Figure 3.2 Average DBH estimates for accessory and main species.

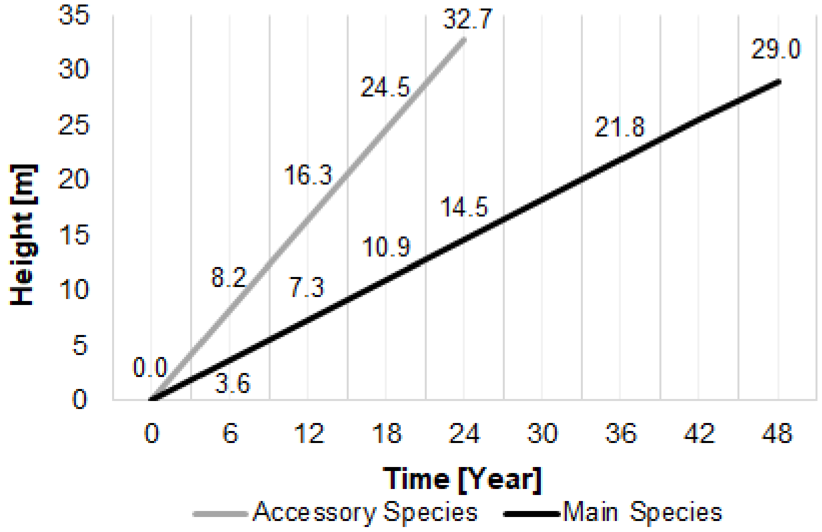

Figure 3.3 Average height estimates for accessory and main species.

DBH projections presented an average yearly increase of 1.68 cm/year for accessory species and 0.85 cm/year for main ones. Height projections, in turn, presented an average yearly increase of 1.36 m/year for accessory species and 0.60 m/year for main ones. From the results of DBH and height throughout the project term, it was possible to estimate the tree volume accumulation per area, and, consequently to plan the harvest cycle for the accessory and main species.

The tree volume per hectare was calculated using the formula proposed Gray (1944) to calculate the parabolic volume for a single tree, and then multiplying by the number of trees per hectare:

$$V_A = V_p * n = \frac{1}{2} h\pi \left(\frac{DBH}{2}\right)^2 * n \tag{3.1}$$

Where:

- $\mathbf{V_A}$ = Total tree volume per area [m^3/ha];
- $\mathbf{V_p}$ = Parabolic volume for a single tree [m^3];
- **n** = Number of trees per hectare: 555 for accessory species and 833 for main species [-/ha];
- **h** = Height [m];
- $\boldsymbol{\pi}$ = 3.1415... [-];
- **DBH** = Diameter at Breast Height [m].

The harvest cycle for accessory species has partial tree cuts in the 12th and 18th years, and a total cutting in the 24th year. For the main species, there are partial cuts in the 18th, 24th and 36th years, and the final cutting in the 48th, when all standing trees are harvested, allowing the beginning of a new cycle.

Tree harvesting cycle may be redefined according to the soil and climatic conditions. In regions with favorable climate and fertile soil, the cuttings could be anticipated, depending on the information provided by the continuous forest inventory (e.g., confirmation of growth stagnation). While recognizing that optimal forest management plays a relevant role on the economic results of a forestry-based business, the focus of the present work is on the processes after harvesting. For this reason, fixed-term regimes for harvesting were considered, as a matter of simplification.

Figures 3.4 and 3.5 present the projected accumulated tree volume per hectare for accessory and main species, considering the tree production (volume gains) and harvesting (volume losses). Losses from plantation problems are minimized by periodic monitoring and replacement of defectives trees and, therefore, they were not accounted.

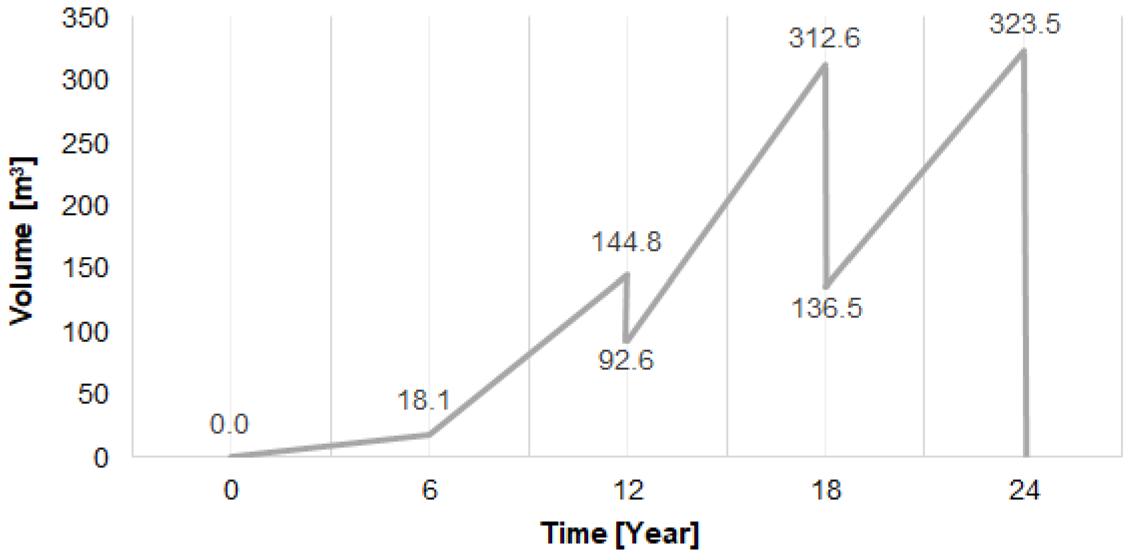

Figure 3.4 Accessory species accumulated tree volume per hectare.

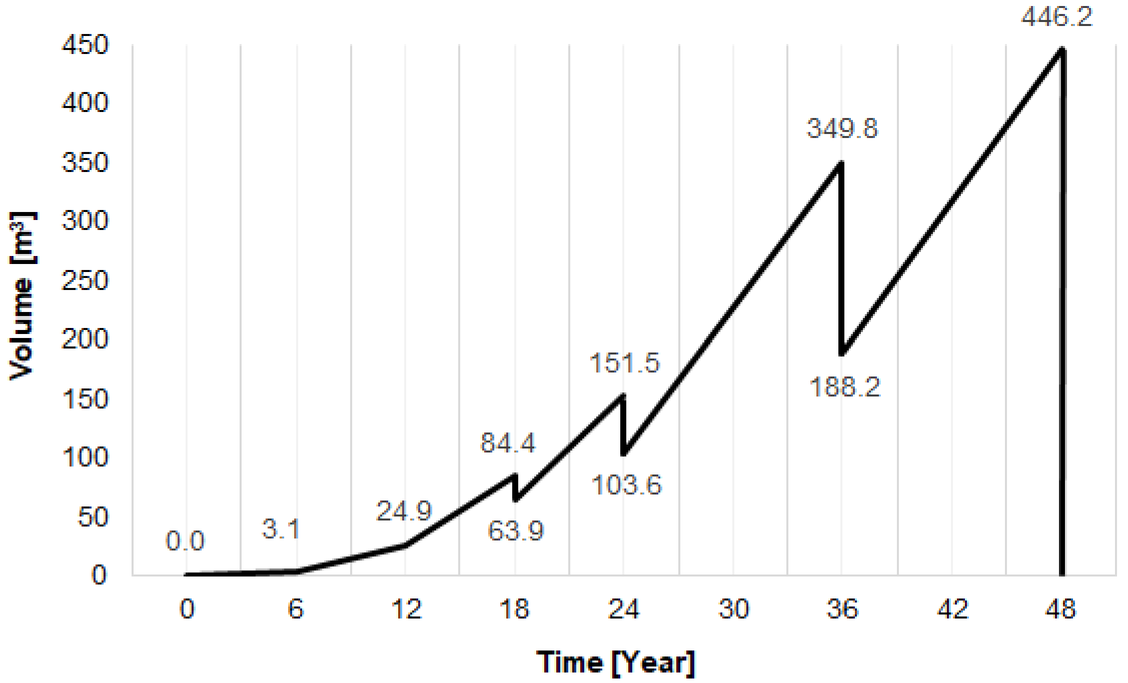

Figure 3.5 Main species accumulated tree volume per hectare.

Finally, Table 3.3 summarizes the data regarding tree production, harvest cycles and total tree volume after harvesting:

Table 3.3 Tree production, harvest cycles and accumulated tree volume per hectare.

Time [Year]	Tree Production		Harvest Cycles - Cut Volumes		Total Tree Volume after Harvesting	
	Accessory Species [m^3/ha]	Main Species [m^3/ha]	Accessory Species [m^3/ha]	Main Species [m^3/ha]	Accessory Species [m^3/ha]	Main Species [m^3/ha]
6.0	18.1	3.1	0	0	18.1	3.1
12.0	144.8	24.9	52.2	0	92.6	24.9
18.0	312.6	84.4	176.1	20.5	136.5	63.9
24.0	323.5	151.5	323.5	47.9	0	103.6
36.0	0	349.8	0	161.6	0	188.2
48.0	0	446.2	0	446.2	0	0

3.2.3 Forest-based products, costs and market prices

All the yield from the tree harvests is processed and transformed in sawn wood and the remains from this process is allocated as biomass for energy purposes (BEP). These products represent the key income sources of the reforestation project. Additionally, carbon credits generated by emission reductions from the forest growth are also accounted as possible source of income (Section 3.2.4).

Sawing consists of transforming circular cross-section harvested tree (tree logs) in rectangular cross-section pieces (sawn wood). This geometric difference between the tree logs and sawn wood, associated with the presence of bark and profiles flaws on tree logs, impacts the sawing process conversion efficiency. According to Murara et al. (2013), the conversion efficiency for conventional sawing of *Pinus taeda* logs may vary from 37.03% to 46.75%. The same authors analyze a more promising technique, known as scheduled sawing, obtaining a better efficiency range: from 44.93% to 63.58%.

For the present work, it was considered the use of the scheduled sawing technique, with an average conversion efficiency of 55%. This value is consistent with the technique efficiency range and with the efficiency range presented by UNECE and FAO (2010) for sawing process conversion. Table 3.4 presents the resulting production of sawn wood and sawing remains per hectare:

Table 3.4 Sawn wood and debris production per hectare.

Time [Year]	Accessory Species			Main Species		
	Harvested Volume [m^3]	Sawn Wood Production [m^3]	Sawing Remains [m^3]	Harvested Volume [m^3]	Sawn Wood Production [m^3]	Sawing Remains [m^3]
12	52.2	28.7	23.5	0	0.0	0.0
18	176.1	96.9	79.2	20.5	11.3	9.2
24	323.5	177.9	145.6	47.9	26.3	21.6
36	0	0.0	0.0	161.6	88.9	72.7
48	0	0.0	0.0	446.2	245.4	200.8

The sawing remains were allocated as BEP in two different forms: debris and pallet. Debris are the sawing remains by themselves, not requiring any other process to be produced. Pellet is the a homogeneous solid biomass in uniformly sized cylindrical shapes (Spelter and Toth, 2009). It is the outcome of the *pelletization* process, which dries and compact wood biomass, providing pellets with higher energy density, lower moisture content and higher market prices if compared with non-processed biomass (i.e., sawing debris). Pellets are generally sold in tons, thus, a conversion ratio of 0.445 t/m^3 (UNECE and FAO, 2010) was used to calculate the pellet output (in mass) per wood volume input.

Table 3.5 introduces the production costs and market prices of all forest product:

Table 3.5 Forest-based products production costs and market prices.

Forest-based Product	**Reference Unit**	**Costs[a][b] [BRL]**	**Inflation[c] [%]**	**Adjusted Costs [BRL]**	**Adjusted Costs[d] [USD]**	**Market Price[e][f][g][h] [USD]**
Sawn Wood - Accessory Species	m^3	R$ 52.80	34.23%	R$ 70.87	$22.20	$450.00
Sawn Wood - Main Species	m^3	R$ 52.80	34.23%	R$ 70.87	$22.20	$938.08
Debris	m^3	R$ 0.00	-	R$ 0.00	$0.00	$12.88
Pellet	t	R$ 80.44	35.88%	R$ 109.30	$34.24	$137.65

[a] Sawn wood production costs for accessory and main species were obtained from Manhiça et al. (2013);

[b] Costs for pellet production were obtained from Sander (2011);

[c] Producer Price Index (IPP) for wood-based products (IBGE, 2018);

[d] Exchange rate = 3.1919 BRL/USD, equals to 1-year average rate, from 01/2017 to 12/2017 (Central Bank of Brazil, 2018).

[e] Sawn wood market price for accessory species was calculated based on 1-year (01/2017 - 12/2017) average international prices for *Khaya* sawn wood, from ITTO Market Information Service (ITTO, 2018);

[f] Sawn wood market price for main species was calculated based on 1-year (01/2017 - 12/2017) average local prices for *Ipê* sawn wood, from ITTO Market Information Service (ITTO, 2018);

[g] Debris market price was calculated based on the 1-year (01/2017 - 12/2017) average prices (in BRL) of *Eucalyptus* wood for energetic purposes, from the IEA Forestry Markets Report (Agricultural Economics Institute, 2018). Then, the price was converted into USD using an exchange rate = 3.1919 BRL/USD;

[h] Pellet market price was calculated based on the 1-year (01/2017 - 12/2017) average prices of exported densified biomass fuel, from the U.S. Monthly Densified Biomass Fuel Report (U.S. Department of Energy, 2018).

Sawn wood and pellet production costs were obtained in *Brazilian Reais* (BRL or R$) and then adjusted by the accumulated inflation (from January/2012 to December/2017 for sawn wood and from January/2011 to December/2017 for pellet). The conversion from BRL to USD (U.S. Dollars or $) was performed using the Brazilian official exchange rate (Central Bank of Brazil, 2018). No production costs were addressed for debris production, as they are a direct by-product from sawing process.

Due the lack of current and reliable information regarding the sawn wood market prices for all studied tree species, the authors decided to use a proxy value for the accessory species and another proxy value for the main ones. The price of accessory species sawn wood considered the international price of *Khaya* sawn wood, provided by the International Tropical Timber Organization - ITTO (ITTO, 2018). The price of main species sawn wood accounted for the *Ipê* sawn wood local price, also provided by ITTO (2017).

Debris market price accounted for the *Eucalyptus* price for energy purposes, provided by the Agricultural Economics Institute, Brazil (Agricultural Economics Institute, 2018). This price was obtained first in BRL (R$41.11 per m^3) and then converted to USD (Central Bank of Brazil, 2018). Finally, pellet price considered the international prices of densified biomass fuel, provided by the U.S. Department of Energy (U.S. Department of Energy, 2018).

3.2.4 Carbon credits

The carbon credits generated by the forest biomass accumulation were calculated following the directives provided by United Nations Framework Convention on Climate Change (UNFCCC) to estimate temporary Certified Emission Reductions (tCERs) from reforestation projects (Galinato et al., 2011; UNFCCC, 2015). This type of carbon credit accounts for the forest carbon stock at a verification date and are valid for 5 years. After 5 years, new verification is performed, forest carbon stock is updated and new tCERs can be issued (Galinato et al., 2011).

The present study accounted for emission reduction from both above and below-ground biomass. Due to lack of information, the emissions generated by forest management activities, sawn wood production and pellet production were not discounted from the emission reductions. The accumulated tree volume from accessory and main species (Figures 3.4 and 3.5) were considered to calculate the above-ground biomass. The below-ground biomass was calculated using a root-to-shoot ratio of 0.37, proposed by Fittkau and Klinge (1973) and IPCC (2006) for tropical rainforests. The issuing period of tCERs was limited to 45 years in order to fit within the project term (48 years). Thus, the first issue occurs at the 5th year of the reforestation project and the last one at the 40th year.

Table 3.6 introduce the issuing chronogram as well as the expected income from tCERs. A tCER price of $0.22 was considered (European Energy Exchange AG, 2018).

Table 3.6 tCER issuing chronogram and income.

Year	Forest Biomass			Temporary Certified Emission Reductions			
	Total Tree Volume(a) [m^3/ha]	Above-Ground Biomass(b) [t/ha]	Below-Ground Biomass(c) [t/ha]	Total Biomass [t/ha]	Total Carbon(d) [t/ha]	Total tCER(e) [-/ha]	Income tCER(f) [USD/ha]
Base	0.00	0.00	0.00	0.00	0.00	0.00	$0.00
5	25.46	15.28	5.65	20.93	9.84	36.04	$7.93
10	123.32	73.99	27.38	101.37	47.64	174.58	$38.41
15	257.25	154.35	57.11	211.46	99.39	364.17	$80.12
20	292.13	175.28	64.85	240.13	112.86	413.55	$90.98
25	124.12	74.47	27.55	102.03	47.95	175.71	$38.66
30	226.7	136.02	50.33	186.35	87.58	320.92	$70.60
35	329.28	197.57	73.10	270.67	127.21	466.14	$102.55
40	274.2	164.52	60.87	225.39	105.93	388.17	$85.40
45	End of 45-year term – No tCERs are issued						

(a) Accessory and main species accumulated biomass;

(b) Estimated from total tree volume using biomass density of 0.6 t/m^3 (UNFCCC, 2015);

(c) Estimated below-ground biomass using a root-to-shoot ratio of 0.37 for tropical rainforests (Fittkau and Klinge, 1973; IPCC, 2006);

(d) Estimated from total biomass using carbon/biomass ratio of 0.47 tC/tBiomass (UNFCCC, 2015);

(e) Estimated from total carbon mass C/$CO_{2eq.}$ ratio of 3.664 $tCO_{2eq.}$/tC (Haynes, 2012).

(f) The tCER price was calculated based on the 1-year (01/2017 - 12/2017) CER Futures values, provided by European Energy Exchange AG (2018).

3.2.5 Target markets, logistics costs and taxes

Two different target markets were considered, local (Brazil) and external (Europe), and evaluated regarding their logistics costs and the taxation. Table 3.7 shows the distances and values assumed for each forest-based product for each market:

Table 3.7 Forest-based products logistics costs per target market.

Product	Reference Unit	Market	Road Distance [km]	Price per km(d) [USD cents/km]	Road Costs [USD]	Shipping Costs(e) [USD]	Total Costs [USD]
Sawn Wood	m^3	Local	400(a)	5.580 ¢	$22.32	-	$22.32
		External	600(b)	4.736 ¢	$28.41	$12.83	$41.24
Debris	m^3	Local	25(c)	24.077 ¢	$6.02	-	$6.02
Pellet	t	Local	400(a)	9.299 ¢	$37.20	-	$37.20
		External	600(b)	7.893 ¢	$47.36	$18.95	$66.31

(a) Distance from project site to Vitória da Conquista, Brazil;

(b) Distance from project site to Vitória port, Brazil;

(c) Distance from project site to the nearest urban area;

(d) The price per km was obtained in BRL from the Brazilian National Index for Transportation Costs from Non-Fractionated Loads (INCT-L) (Associação Nacional do Transporte de Cargas e Logística, 2018) and converted to USD using an exchange rate of 3.1919 BRL/USD (Central Bank of Brazil, 2018);

(e) The shipping price was based on a shipping quote from Vitória port (Brazil) to Rotterdam port (Netherlands) for a 40’ high-cube container (iContainers, 2018; SeaRates LP, 2017).

The total costs presented by Table 3.7 are expressed in USD per product's reference unit. For local market, sawn wood and pellet logistics and transportation costs accounted for the distance from the project site to Vitória da Conquista (~400 km), where there is an important woodworking industrial hub. For the external market, it was considered the distance from the project site to the port of Vitória (~600 km) and then the shipping costs from Vitória port to Rotterdam port (Netherlands). To maintain a certain level of profitability, debris are available just for local market, limited to a road distance range of 25 km.

Table 3.8 presents the tax incidence over each target market and over carbon credits revenues. One state tax (i.e., ICMS) and five federal taxes (i.e., PIS, COFINS, IRPJ, CSLL and Funrural) are applicable for forestry businesses. However, due to some tax benefits provided by Brazilian Government to exported products, just three of them (i.e., IRPJ, CSLL and Funrural) are applicable for the external market (Brazilian Ministry of Industry Foreign Trade and Services, 2017). The tax regime for carbon credit revenues was based on the study made by Silva (2015).

Table 3.8 Tax incidence for forest-based products (local e external markets) and carbon credits.

Tax Name	**Acronym**	**Calculation Base**	**Rate**		
			Local Market	**External Market(f)**	**Carbon Credits(g)**
State Tax over the Circulation of Goods and Services(a)	ICMS	Product Market Price	18.00%	Not applicable	
Contribution to the Social Integration Plan(b)	PIS	Gross Income	1.65%	Not applicable	
Contribution for Social Security Financing(b)	COFINS		7.60%	Not applicable	
Corporate Income Tax(c)	IRPJ	Net Profit	15% - until R$240,000.00 annual profit 25% - over R$240,000.00 annual profit		
Social Contribution over Net Profit(d)	CSLL		9.00%		
Assistance to the Rural Worker Program(e)	Funrural		1.30%		

(a) Tax rate and calculation base defined by Government of the State of Bahia (1996);

(b) Tax rates and calculation base defined by the Federative Republic of Brazil (2003);

(c) Tax rates and calculation base defined by the Federative Republic of Brazil (1977), according the real net profit rule;

(d) Tax rates and calculation base defined by the Federative Republic of Brazil (2008), according the real net profit rule;

(e) Tax rates and calculation base defined by the Federative Republic of Brazil (1991);

(f) Tax exemption program for Brazilian exports (Brazilian Ministry of Industry Foreign Trade and Services, 2017);

(g) Certified Emission Reductions tax regime assessment made by Silva (2015).

3.2.6 Business scenarios and economic assessment

Eight business scenarios were analyzed according to different combinations of three variables: type of BEP – Debris (D) or Pellet (P); not accounting (X) or accounting (C) for revenues from carbon credit –; and target market – Local (L) or External (E) (Table 3.9).

Table 3.9 Forestry business scenarios.

Scenario	BEP	Carbon	Market
DXL	D - Debris	X - No	L - Local
DCL	D - Debris	C - Yes	L - Local
DXE	D - Debris	X - No	E - External
DCE	D - Debris	C - Yes	E - External
PXL	P - Pellet	X - No	L - Local
PCL	P - Pellet	C - Yes	L - Local
PXE	P - Pellet	X - No	E - External
PCE	P - Pellet	C - Yes	E - External

For each scenario, the consolidated costs (from reforestation, production and logistics), incomes (from sawn wood, BEP and carbon credits, when applicable) and due taxes were estimated considering the total productive area (250 hectares) and the 48-year project term.

The scenarios were also evaluated and ranked according its Net Present Value (NPV), Internal Rate of Return (IRR) and Payback period (Allen, 1991). NPV is the sum of the individual discounted values of the yearly cash flows, given by:

$$NPV = \sum_{t=1}^{T} \frac{F_t}{(1+r)^t} = \sum_{t=1}^{T} \frac{I_t - E_t}{(1+r)^t} \qquad (3.2)$$

Where:

- **t** = Time [year];
- $\mathbf{F_t}$ = Cash flow at time **t** [USD];
- **r** = Discount rate [-];
- **T** = 48 years (final year);
- $\mathbf{I_t}$ = Income at time **t** [USD];
- $\mathbf{E_t}$ = Expenses (i.e., costs and taxes) at time **t** [USD].

In other words, the NPV is the project discounted profit (or loss) considering its total duration. To calculate the NPV for the eight scenarios, a 8% discount rate (r = 8%) was selected, based on the discount rate used by Cubbage et al. (2007) for reforestation projects in South America.

The IRR represents the discount rate at which the project breaks even and is a metric of potential profitability of a project. Its calculation is done by finding the resulting discount rate for a NPV equals to zero:

$$NPV = 0 = \sum_{t=1}^{T} \frac{F_t}{(1+IRR)^t} \tag{3.3}$$

Finally, payback time measures the time needed for the cumulative project investment and other early project expenditures to be compensated by the cumulative net incomes. Thus, the lower is the payback time, the more attractive a project seems to be.

3.3 Results

Tables 3.10 and 3.11 show the estimated costs, incomes and taxes over the project 48-year duration under the different business scenarios. For all, the reforestation costs are the most relevant, ranging from 55.45% to 71.59% of all costs. The costs regarding sawn wood production and transportation come next, assuming a greater value in external market scenarios ($846,303.23) than in internal market scenarios ($593,858.08) due the higher logistics costs (Table 3.7).

In regard to BEP costs, scenarios employing pellets presented results substantially higher ($488,768.53 for external market and $347,266.38 for internal market) than scenarios employing debris ($65,695.77). These higher costs, however, are compensated by pellets incomes, which are ten times higher than debris ones. In all scenarios, sawn wood is the main source of income, accounting from 91.62% to 99.13% of all revenues. Carbon credits represented about 0.20% of income share only.

For internal market scenarios, ICMS (~42%) and IRPJ (~27%) were responsible for most of the tax burden. For external market scenarios, which are exempted from ICMS, COFINS and PIS (Table 3.8), IRPJ (~69%) and CSLL (~25%) represented the majority of the taxes expenses. The tax benefits directed to external market resulted in a great decline over the total taxes expenses, accounting for 45.62% to 47.28% of tax reduction.

The results regarding NPV and IRR are presented by Figure 3.6:

Table 3.10 Costs and incomes estimates for each business scenario.

Scenario	Costs - Present Value(a)				Incomes - Present Value(a)			
	Reforestation [USD]	**Sawn Wood [USD]**	**BEP [USD]**	**Total Cost [USD]**	**Sawn Wood [USD]**	**BEP [USD]**	**Carbon Credits [USD]**	**Total Income [USD]**
PCE	$1,661,596.34	$846,303.23	$488,768.53	**$2,996,668.10**	$7,477,064.72	$669,132.76	$14,821.88	**$8,161,019.36**
PXE	$1,661,596.34	$846,303.23	$488,768.53	**$2,996,668.10**	$7,477,064.72	$669,132.76	$0.00	**$8,146,197.48**
DCE	$1,661,596.34	$846,303.23	$65,695.77	**$2,573,595.34**	$7,477,064.72	$65,695.77	$14,821.88	**$7,557,582.37**
DXE	$1,661,596.34	$846,303.23	$65,695.77	**$2,573,595.34**	$7,477,064.72	$65,695.77	$0.00	**$7,542,760.49**
PCL	$1,661,596.34	$593,858.08	$347,266.38	**$2,602,720.80**	$7,477,064.72	$669,132.76	$14,821.88	**$8,161,019.36**
PXL	$1,661,596.34	$593,858.08	$347,266.38	**$2,602,720.80**	$7,477,064.72	$669,132.76	$0.00	**$8,146,197.48**
DCL	$1,661,596.34	$593,858.08	$65,695.77	**$2,321,150.19**	$7,477,064.72	$65,695.77	$14,821.88	**$7,557,582.37**
DXL	$1,661,596.34	$593,858.08	$65,695.77	**$2,321,150.19**	$7,477,064.72	$65,695.77	$0.00	**$7,542,760.49**

(a)8% yearly discount rate (r = 8%).

Table 3.11 Due taxes estimates for each business scenario.

Scenario	Taxes - Present Value(a)						
	ICMS [USD]	**PIS [USD]**	**COFINS [USD]**	**IRPJ [USD]**	**CSLL [USD]**	**Funrural [USD]**	**Total Tax [USD]**
PCE	$0.00	$0.00	$0.00	$1,257,805.64	$455,419.33	$106,093.25	**$1,819,318.22**
PXE	$0.00	$0.00	$0.00	$1,256,523.96	$454,957.92	$105,900.56	**$1,817,382.44**
DCE	$0.00	$0.00	$0.00	$1,219,428.37	$441,603.52	$98,248.58	**$1,759,280.47**
DXE	$0.00	$0.00	$0.00	$1,218,146.69	$441,142.11	$98,055.89	**$1,757,344.69**
PCL	$1,466,315.55	$110,218.06	$507,671.02	$937,720.31	$340,188.61	$87,031.16	**$3,449,144.71**
PXL	$1,466,315.55	$110,218.06	$507,671.02	$936,438.63	$339,727.20	$86,838.47	**$3,447,208.93**
DCL	$1,357,696.89	$102,053.55	$470,064.84	$898,547.38	$326,086.36	$80,598.52	**$3,235,047.54**
DXL	$1,357,696.89	$102,053.55	$470,064.84	$897,265.70	$325,624.95	$80,405.83	**$3,233,111.76**

(a)8% yearly discount rate (r = 8%)

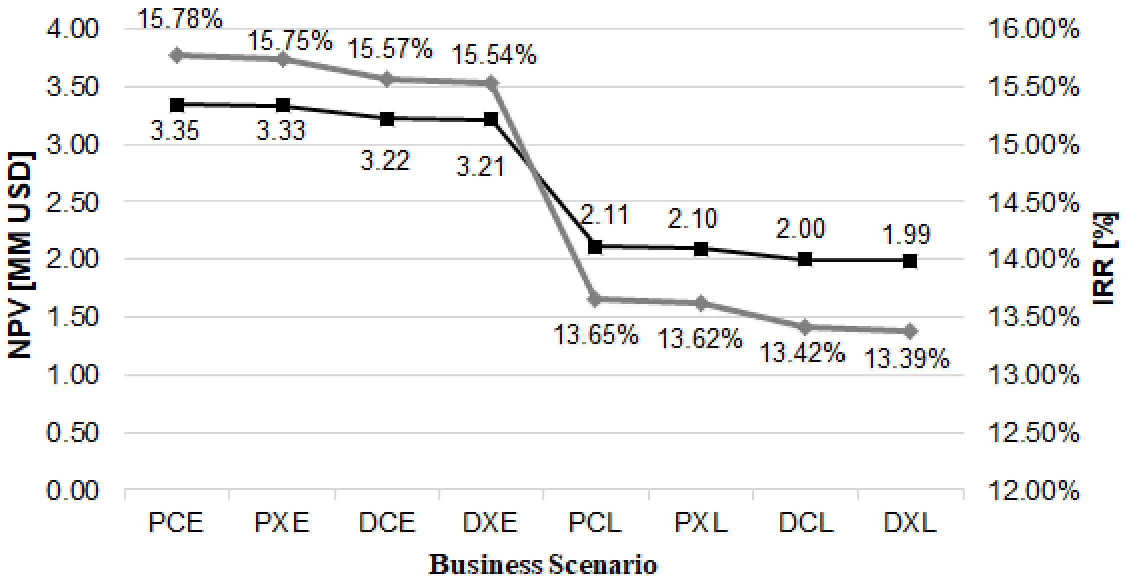

Figure 3.6 NPV and IRR results for the eight business scenarios.

Scenarios aiming the external market presented greater economic returns compared with the local market ones. The results for NPV were between 58.60% and 61.52% higher for external market scenarios. In regard to IRRs, all external market scenarios had IRR higher than 15% (from 15.54% up to 15.78%) while internal market scenarios presented IRR values varying from 13.39% to 13.65%.

Finally, most scenarios had payback times equal to 18 years, except scenarios DXL and DCL which payback times were 24 years.

3.4 Discussion

Based on the business scenarios results, it is possible to verify that the target market was the most economically relevant variable. The change from internal to external market implied in elevation of logistics costs for pellet and sawn wood and made the total costs from external market scenarios to be between 10.88% and 15.14% higher than their local market equivalents.

These extra costs, however, were more than offset by the tax discount provided by Brazilian government to exported products (Brazilian Ministry of Industry Foreign Trade and Services, 2017). Figure 3.7 illustrates this offset by allocating the scenarios incomes into costs, taxes and profits.

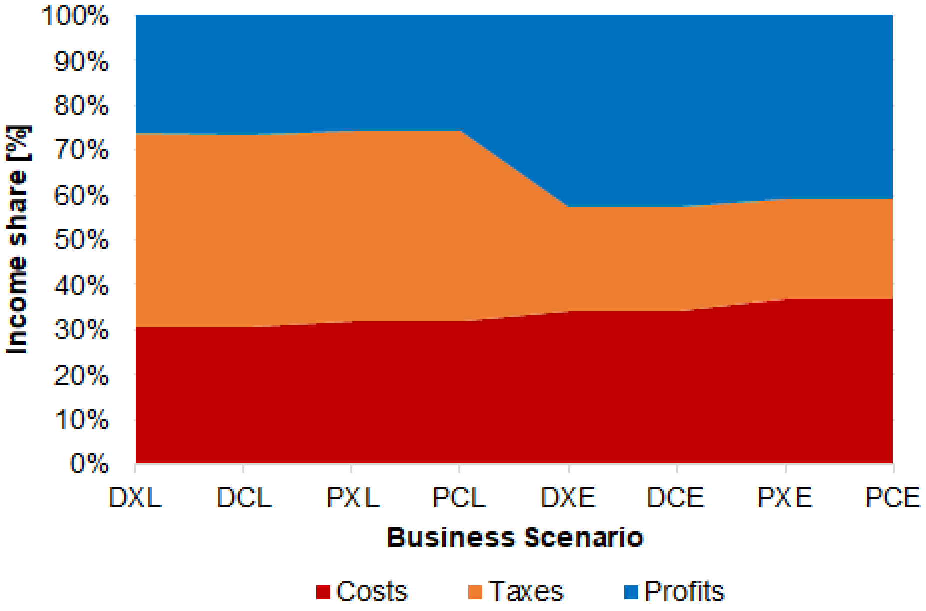

Figure 3.7 Income allocation by costs, taxes and profits.

As can be noticed by Figure 3.7, most of the tax reductions granted for external market scenarios were converted into profits. As an outcome from this conversion, NPV and IRRs of external market scenarios were boosted by nearly 60% and 2.14 percentage points (pp), respectively.

The type of BEP and carbon credit accounting were less relevant. The scenarios using pellet as BEP presented NPV results from 3.73% to 5.42% higher compared to debris ones. For IRR, choosing pellet instead of debris represented an average addition of 0.22 pp. Accounting for carbon credits revenues represented small NPV increments, from 0.39% to 0.65%, and an average IRR growth of 0.03 pp.

Payback results are strongly correlated with the forests harvesting years, when the great majority of the incomes are generated. Most of the scenarios reaches their investment break-even point at the18th year, when occurs the second tree harvesting (Table 3.3). DCL and DXL were the only scenarios that reached the break-even point at the third harvesting (24th year).

It is worth mentioning, though, that even after achieving the break-even point at the second harvesting, scenarios PXL and PCL kept negative NPV results until the third harvesting, when, finally, the NPV results maintained positive until the end of the project period. For all cases, choosing local market (with no tax exemption) and less profitable BEP (debris) decreased their yearly cash flows and pushed the payback time to the third harvesting period.

Irrespectively of the scenario, sawn wood is the main source of income and, thus, results are heavily dependent upon changes of its market prices. In order to understand how intense this impact is, Figure 3.8 presents a sensitivity analysis, for scenario PCE, of the IRR response from sawn wood prices changes. For this analysis, the sawn wood prices from accessory species and main species varied by the same proportion.

Figure 3.8 Sawn wood prices sensitivity analysis (PCE scenario).

As can be noticed, for PCE scenario, the IRR had a linear response from sawn wood prices variations. In fact, the same behavior was also verified for the remaining scenarios. For all of them, 5% of price reduction corresponded to an average IRR reduction of 0.42 pp. A price increase of 5%, in turn, resulted in an average IRR growth of 0.37 pp. Thus, it is possible to assume that the reforestation project is economically robust, able to maintain levels of IRR greater than 11.7% (DXL scenario) even after a 20% decrease in sawn wood prices.

The accounting of carbon credits revenues had very small contribution to total income. The reason is the low prices currently applied for CERs (European Energy Exchange AG, 2018), which can be explained by the persistent low CERs demand and the uncertainties about the application of the Kyoto Protocol's Clean Development Mechanism (CDM) in the Paris Agreement (or similar mechanism). Even so, there is a growing number of regional and national carbon pricing initiatives, which practice a wide scale of carbon prices, ranging from less than \$1 up to \$126 per ton of $CO_{2eq.}$ (World Bank and Ecofys, 2017).

Figure 3.9 simulates how the elevation of carbon credits prices would affect IRR results for PCE scenario. Analogously to Figure 3.8, a sensitivity analysis for the IRR was performed, changing the market prices of carbon credits. The prices ranged from $0 to $50 per carbon credit (ton of CO_{2eq}).

The IRR response associated to the variations of carbon credits prices was also linear for PCE and the remaining scenarios. On average, every 1-dollar increase on carbon credit prices reflected in a IRR elevation of 0.13 pp. In this sense, the rise of carbon prices may turn carbon credits into a more relevant source of income.

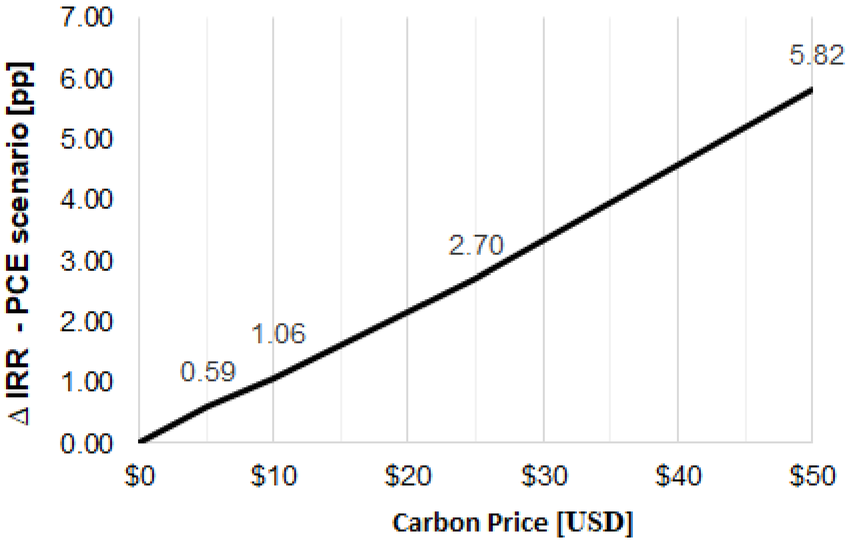

Figure 3.9 Carbon credits prices sensitivity analysis (PCE scenario).

About BEP options, pellet performed better than debris. Aside from the low profitability, debris low price limits its market scope, as it is economically unviable its transportation to distances higher than 50 km. In this vein, transforming debris into pellets enables transportation over long distances, seasonal storage and higher profits (Wahlund et al., 2004).

3.5 Conclusion

The present chapter evaluates NPV, IRR and payback period of a mixed forestry project adding to the available literature. The economic assessment considering many different business scenarios proves to be a useful tool to support the design of the forestry business plan. The identification of the costs, tax regime, revenues, economic returns and payback time allows forest managers and investors to identify the business solution which best-fits their expectations.

Tax regime plays an important role in this type of entrepreneurship and understanding its functioning is imperative. The tax exemptions granted for external market scenarios resulted in NPV growth of 60% and extra 2.14 pp for IRR, compared with local market scenarios.

Regarding the most relevant product, sawn wood, the studied forestry project remained economically robust against changes of its market prices. Price drops down to 20% resulted in average IRR reduction of 1.68 pp, which still maintains IRR levels over 11.7% for all scenarios.

Choosing pellet instead of debris as BEP had small, but not irrelevant, benefits. It increased scenarios NPVs from 3.73% to 5.42% and contributed with an additional 0.22 pp for IRRs. Additionally, pellet is a more versatile form of BEP than debris, which allows transportation over long distances and seasonal storage.

Carbon credits don't represent a relevant source of income considering the current low prices of CERs. Still, the implementation of Paris Agreement in 2020 and the creation of new markets will likely push the carbon prices to much higher levels, which may turn carbon credits into a more interesting source of revenues.

Payback is strongly correlated with the harvesting years, when most of revenues are generated. Most scenarios achieve the break-even point at the second tree harvesting, after 18 years. Only the two less profitable scenarios (DCL and DXL) reaches the break-even point at the third harvesting, after 24 years. The choice for debris and local market implied in reduced yearly cash flows and pushed the payback time to the third harvesting period.

PCE presented the best economic results among the other scenarios, with a NPV of 3.35 million USD, IRR of 15.78% of and payback period of 18 years. These results, in special the IRR, are in line with the ones found in literature. In fact, the most profitable scenarios presented IRR values close to the ones found for *Pinus* plantation in Brazil. It shows that mixed tropical forestry projects have the potential to be economically viable.

For further works, the evaluation of how different forest management strategies would impact the business scenarios results is encourage.

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4 ASSESSING BONN CHALLENGE’S IMPACTS IN AGRICULTURE: A GENERAL EQUILIBRIUM ANALYSIS

4.1 Introduction

Forests cover about 30.6% of globe’s total land area (FAO, 2016) and provides many relevant ecosystem services, such as soil nutrient cycling, erosion control, watershed protection, conservation of natural biodiversity and climate regulation. Due their magnitude in area, they also play a relevant role at global carbon cycle, working as natural sink and storage.

According to Pan et al. (2011), world’s forests store about 3,151 ± 242 $GtCO_{2eq}$[1] and represents one of the major carbon sinks for anthropogenic emissions, absorbing 4.0 ± 2.9 CO_{2eq}[1] per year. Forest carbon sink ability could be much higher (up to 14.8 ± 2.5 CO_{2eq}[1] per year) if it was not for the great emissions from deforestation and forest degradation in the tropics. Beyond the emissions, deforestation and forest degradation lead to a reduction in the ecosystem goods and services that forests provide, triggering biodiversity loss, depleted soils, food insecurity, and reduced availability of clean water, which increase the vulnerability to climate and market shocks for the human populations that inhabit and depend on forested landscapes (CCAD and GIZ GmbH, 2017; Sutton et al., 2016; Turner et al., 2016; Uriarte and Chazdon, 2016).

Data from the Global Forest Watch (2018) shows that from 2001 to 2017, there was a total 337 Mha of tree cover loss globally, accounting for 90.4 CO_{2eq}[1] in greenhouse gas (GHG) emissions. Besides that, between 2000 and 2012, more than 185 Mha of forests suffered from partial canopy cover loss, with tropical forests accounting for 84% of this area (FAO, 2016). To complete this picture, Minnemeyer et al. (2014) identified more than 2 billion hectares worldwide that offer opportunities for restoration, an area two times bigger than Europe.

Given this critical scenario of land degradation around the world, it was not for nothing that forest restoration were given highlight attention recently and have been addressed in many of the major global pledges, such as the 20 Aichi Biodiversity Targets (UNEP, 2010), Rio+20 Land Degradation Neutrality Goal (UN, 2012), the New York Declaration on Forests (UN Climate Summit, 2014), the Sustainable Development Goals (UN, 2015a) and the Paris Agreement (UN, 2015b). As a vehicle to achieve the myriad of restoration targets under one initiative, the Bonn Challenge was created (GPFLR and IUCN, 2018; Verdone and Seidl, 2017).

The challenge was originated launched in 2011 by the Government of Germany and the International Union for Conservation of Nature – IUCN, and represents a global effort to bring 150 million hectares of the world's deforested and degraded land into restoration by 2020, and another 200 million hectares by 2030 (GPFLR and IUCN, 2018). In addition to global restoration pledges, Bonn Challenges also embraces regional political initiatives, like the African Forest Landscape Restoration Initiative – AFR100 (NEPAD, 2018) and the South American Initiative 20x20 (Reinecke and Blum, 2018; WRI, 2018). To the present day, 63 commitments have been made, accounting for 169 million hectares restoration by 2030 (see Appendix B).

Despite its global nature and large scale, the potential impacts in economy from the implementation of Bonn Challenge's restoration activities have been little explored. According to a publication from FAO and UNCCD (2015), the cost of restoring 350 million ha of forest until 2030 are estimated at US$ 837 billion, around US$ 42 billion per year, considering the period 2011-2030. While acknowledging the lack of empirical data regarding the positive economic impacts from broad scale ecological restoration activities, the same publication suggests that these cost could be overcompensated by the products and ecosystem services provided by the restored area (FAO and UNCCD, 2015).

IUCN (2012) estimated that restoring 150 million hectares of degraded and deforested lands would generate approximately USD 84 billion per year in net benefits. approximately 90% of this value is potentially tradable, which could bring direct additional income opportunities for rural communities. CCAD and GIZ GmbH (2017) go beyond and estimate that achieving the 350-million-hectare goal will generate about USD 170 billion per year in net benefits.

By accounting for restoration direct costs and known benefits from ecosystem services, De Groot et al. (2013) estimated that internal rates of return from biome restoration may range from −14% (coastal systems) to 59% (grasslands), for a 20-year period. In all cases, the benefit-cost ratios were positive for all biomes, indicating benefits exceeded costs in all cases. Differently from IUCN (2012), the positive economic impacts from restoration were based on the database developed by De Groot et al. (2012), which mostly accounts for non-market benefits from ecosystem services.

In a recent work, Verdone and Seidl (2017) presented a methodology for valuing the net benefits of achieving the Bonn Challenge. They evaluated the net benefits from the challenge accomplishment under different social discounting regimes, different valuations of public goods, and different time horizons. According to their results, the challenge fulfilment would cost 299 billion U.S. dollars and that the net benefit generated could vary from 0.7 and 9 trillion U.S. dollars.

These works contribute in framing some economic aspects and trade-offs from Bonn Challenge implementation, however they evaluated just the direct economic aspects from the global scale restoration effort. The aim of this work is to extend the present literature by exploring the economic impacts from the restoration of 350-million-hectares on other intensive land-use sectors, particularly crops and livestock grazing.

To this end, a global computable general equilibrium model (CGE) was used, considering challenge's timeframe (2011-2030) and focusing the regions with ongoing restoration commitments (i.e., Africa, Asia, Latin America and North America - GPFLR and IUCN, 2018). The analysis focused on changes in land prices, agriculture production and average prices, and regional gross domestic product (GDP). The preference for a CGE model to perform this assessment was due to its intrinsic characteristic of capturing reallocation effects across the economic system.

The remainder of this work is structured as follows. Section 4.2 introduces CGE model structure, data specifications and considerations. It also specifies the policy scenario under evaluation (i.e., Bonn Challenge restoration target). Section 4.3 presents and discuss the results from the estimated by the model. Conclusions are presented by Section 4.4.

4.2 Methodology

4.2.1 CGE model specification

The present study uses the Intertemporal Computable Equilibrium System (ICES) CGE model (Eboli et al., 2010) to simulate the economic impacts from the global scale restoration effort. ICES is a recursive-dynamic, multi-sector, multi-country model based on the core structure of GTAP (Global Trade Analysis Project) model (Hertel, 1997) incorporated with GTAP-E model production side, which provides a more satisfactory representation of the energy and emission sides of economic systems (Burniaux and Truong, 2002). More detailed information about the model is presented in Appendix C.

The model is well-suitable to evaluate climate change impacts in economy and mitigation policies (Bosello et al., 2012; Eboli et al., 2010), allowing, among other things, the inclusion of carbon taxes and an emission trade module to simulate an international carbon market (Parrado and De Cian, 2014).

ICES has also been used to investigate forest mitigation strategies. Michetti and Rosa (2012) investigated the role of forest-based carbon sequestration in a unilateral EU27 emissions reduction. Their results indicate that afforestation and timber management could lead to substantially decrease mitigation policy costs, but, as consequence, it may trigger a leakage effect on timber production, increasing timber extraction in other areas of the world, including the ones with high levels of deforestation. Bosello et al. (2015) evaluated the impacts from introducing avoided deforestation credits into the European carbon market, concluding that this measure would notably lower climate change policy costs in Europe at the same time effectively reducing deforestation activities.

In both cases, land competition between forests and agriculture (i.e., crops and livestock grazing) occurs as changes on the availability of agricultural land based on a business-as-usual (BAU) deforestation scenario. In other words, the conservation or increase of forest area were modelled as a reduction of deforestation at BAU scenario. The studies also consider land as a homogeneous endowment, thereby not accounting for differences regarding soil, geographic position and climate.

The present study used an ICES version developed by Michetti and Parrado (2012), who improved ICES' land use activities information employing GTAP-AEZ land-use Data Base (Lee et al., 2005). Differently from other versions of the model, this extended version (named as ICES-AEZ) directly captures land competition among forestry and agriculture activities by means of by means of a Constant Elasticity of Transformation function (CET), representing landowners' choices. In addition to that, ICES-AEZ accounts for land diversity and distinguishes it into 18 different Agro-Ecological Zones (AEZs). These zones are characterized by specific latitudinal climate regions and Length of Growing Periods (LGP), as presented by Table 4.1.

LGP is defined as the number of days when water availability and prevailing temperatures permit crop and tree species growth (IIASA and FAO, 2000). In GTAP-AEZ, 6 different LGPs are defined at global level according to humidity gradients across the world. These LGPs are then matched with over 3 different climatic zones (tropical, temperate, boreal) to produce the 18 AEZs (Lee et al., 2005).

Table 4.1 Definition of global Agro-ecological zones used in GTAP.
Source: Lee et al. (2005)

LGP in days	Moisture regime	Climate zone	Zone
0-59	Arid	Tropical	AEZ1
		Temperate	AEZ2
		Boreal	AEZ3
60-119	Dry semi-arid	Tropical	AEZ4
		Temperate	AEZ5
		Boreal	AEZ6
120-179	Moist semi-arid	Tropical	AEZ7
		Temperate	AEZ8
		Boreal	AEZ9
180-239	Sub-humid	Tropical	AEZ10
		Temperate	AEZ11
		Boreal	AEZ12
240-299	Humid	Tropical	AEZ13
		Temperate	AEZ14
		Boreal	AEZ15
>300 days	Humid; year-round growing season	Tropical	AEZ16
		Temperate	AEZ17
		Boreal	AEZ18

4.2.2 Model databases and calibration

To implement the present analysis, ICES-AEZ was updated to work with GTAP 8.1 Data Base (Baldos and Hertel, 2012) and its and its corresponding Land Use and Land Cover Data Base (Narayanan et al., 2012). The model was also tuned to simulate global economy by 22 primary factors of production (capital, labor, fishing and fossil fuels natural resources, and 18 AEZs), 12 sectors (forestry, crops, livestock grazing, food industry, coal, oil, gas, oil products, electricity, other industries, services and capital good commodities) and 11 regions. Due databases limitations, model’s base year was set in 2007, but the analysis will consider just the data generated from 2011 to 2030, Bonn Challenge’s period in force.

For African, Asian, Latin American and North American continents, the regions were established by separating the countries which participate in the Bonn Challenge effort (regions B_Asia, B_Africa, B_LatinAmer and B_NAmer) from the countries which do not (regions NB_Asia, NB_Africa, NB_LatinAmer and NB_NAmer). Europe, Oceania and the Rest of the World were considered as one region each, as no country in these regions made any pledge to Bonn Challenge. Appendix D contains a detailed description of the regional aggregation.

The distribution of forest land, cropland and livestock land were directly obtained from the GTAP Land Use and Land Cover Data Base 8.1 file (see Appendix E). Differently from Michetti and Rosa (2012) and Bosello et al. (2015), changes in land use were exogeneous set and the policy implementation was simulated by shocking every year the quantity of AEZs supplied to each land intensive sector (forestry, crops and livestock grazing).

For every year T, the increment of forestry land in one AEZ at a specific region was equally compensated by decreasing land available for crops and livestock grazing for the same AEZ at the same region (Equation 4.1). To balance the land loss between crops and livestock, the shares of land reduction for both sectors were matched for the all AEZs at the all regions (Equation 4.2).

$$\Delta AEZ_{i,R,T_s}^{F} = -\left(\Delta AEZ_{i,R,T_s}^{C} + \Delta AEZ_{i,R,T_s}^{L}\right) \tag{4.1}$$

$$s.t.: \ \%AEZ_{i,R,T_s}^{C} = \%AEZ_{i,R,T_s}^{L} \tag{4.2}$$

where

- i = number of AEZ, from 1 up to 18;
- R = region;
- T_s = shock year, from 2011 until 2030;
- F, C, L = land intensive sectors: Forestry, Crops and Livestock grazing;
- $\Delta \boldsymbol{AEZ}_{i,R}^{F,C,L}$ = absolute variation of AEZ_i for sectors F, C, L at region R;
- $\%\boldsymbol{AEZ}_{i,R}^{C,L}$ = relative variation of AEZ_i for sectors C, L at region R.

Although Equations 4.1 and 4.2 guarantees a balanced distribution of new forests among existing agricultural and livestock areas in all AEZs, this approach doesn’t address the AEZs potentiality for each land-intensive sector. In other words, land allocation for forestation is not performed seeking economical or ecological optimization. The author acknowledge that this is a limitation and that may impact the results.

4.2.3 Policy scenarios

To test the economic impact from Bonn Challenge implementation in crops and livestock sectors, four policy scenarios were designed. The first scenario, named as baseline scenario, represents the no-policy situation, in which the development of global economic is replicated with no implementation of Bonn Challenge commitments by any country. The model is fed with data regarding regional population, employment and gross domestic product (GDP) growths consistent with the Shared Socio-economic Pathway 2 - SSP2, which considers that the world's social, economic, and technological trends do not shift markedly from historical patterns (IIASA, 2016).

The second policy scenario, named as pledged scenario, simulates the increase of 169 Mha of forestland by 2030, in line with the current pledged area under Bonn Challenge's initiative. Time and regional distributions of forestland increments follow countries geographic location and target years from the ongoing commitments presented in Appendix B. Table 4.2 matches this information and presents the resulting increments in forestland for each region in each year:

Table 4.2 Forestland increments (in kha) for pledged scenario, distributed by region and year.

Year	**Region**				
	B_Africa	**B_Asia**	**B_LatinAmer**	**B_NAmer**	
2011	200	0	100	1,500	
2012	200	0	322	1,500	
2013	200	0	322	1,500	
2014	3,843	0	2,375	1,500	
2015	5,543	2,392	3,307	1,500	
2016	7,056	2,392	3,515	1,500	
2017	8,560	2,697	3,528	1,500	
2018	8,999	2,985	3,552	1,500	
2019	8,999	2,985	3,552	1,500	
2020	8,999	2,985	3,552	1,500	
2021	3,746	1,047	1,290	0	
2022	3,746	1,047	1,290	0	
2023	3,746	1,047	1,290	0	
2024	3,746	1,047	1,290	0	
2025	3,746	1,047	1,290	0	
2026	3,746	1,047	1,290	0	
2027	3,746	1,047	1,290	0	
2028	3,746	1,047	1,290	0	
2029	3,746	1,047	1,290	0	
2030	3,746	1,047	1,290	0	**Total**
Total	**90,060**	**26,910**	**37,030**	**15,000**	**169,000**

The third policy scenario, named as goal scenario, extrapolates forestland increments presented by Table 4.2 to achieve Bonn Challenge's goals of restoring 150 million hectares of forest by 2020 and other 200 million hectares by 2030. Geographic distribution for forest area increasing was kept the same from pledge scenario. Table 4.3 introduces the forestland increments of this scenario for each region in each year:

Table 4.3 Forestland increments (in kha) for goal scenario, distributed by region and year.

Year	Region				
	B_Africa	B_Asia	B_LatinAmer	B_NAmer	
2011	320	0	160	2,401	
2012	320	0	516	2,401	
2013	320	0	516	2,401	
2014	6,150	0	3,800	2,401	
2015	8,470	3,827	5,187	2,401	
2016	9,494	3,827	5,519	2,401	
2017	9,494	4,247	5,519	2,401	
2018	9,494	4,380	5,555	2,401	
2019	9,494	4,380	5,555	2,401	
2020	9,494	4,380	5,555	2,401	
2021	13,461	2,993	3,548	0	
2022	13,461	2,993	3,548	0	
2023	13,461	2,993	3,548	0	
2024	13,461	2,993	3,548	0	
2025	13,461	2,993	3,548	0	
2026	13,461	2,993	3,548	0	
2027	13,461	2,993	3,548	0	
2028	13,461	2,993	3,548	0	
2029	13,461	2,993	3,548	0	
2030	13,461	2,993	3,548	0	**Total**
Total	**197,660**	**54,970**	**73,360**	**24,010**	**350,000**

The last scenario, named as global scenario, accounts for the distribution of the 350 million hectares restoration across all continents. The increase in forest area was equally distributed during the years, considering of Bonn Challenge's full period, from 2011 to 2030. The geographic distribution of forestland increments followed the data provided Minnemeyer et al. (2014) regarding the opportunities available in each continent for forest restoration (Table 4.4).

Table 4.4 Forestland total and yearly increments (in kha) for global scenario, distributed by region.

Region	Total Increment	Yearly Increment
B_Africa	74,903	3,745
B_Asia	26,691	1,335
B_LatinAmer	55,692	2,785
B_NAmer	38,082	1,904
NB_Africa	26,827	1,341
NB_Asia	37,496	1,875
NB_LatinAmer	9,706	485
NB_NAmer	8,544	427
Europe	56,315	2,816
Oceania	15,744	787
Total	**350,000**	**17,500**

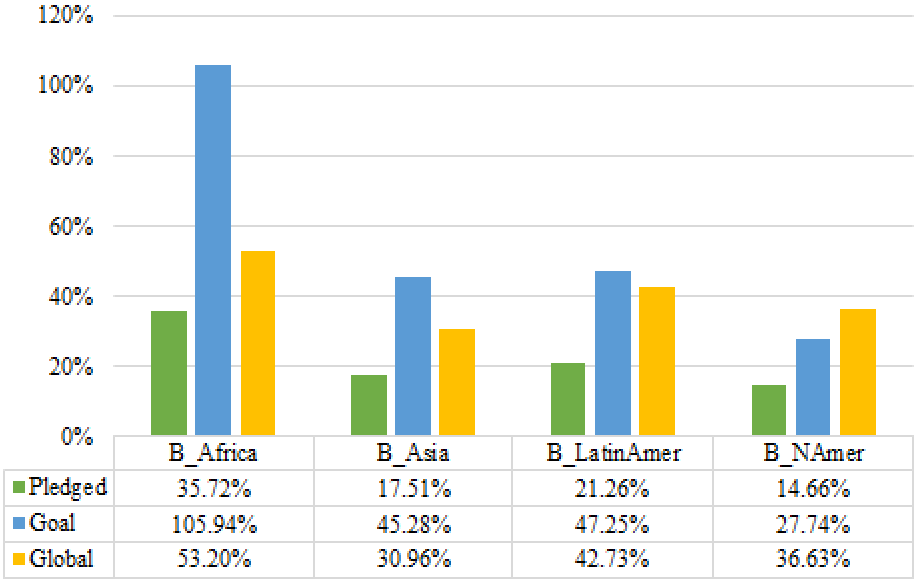
For both pledged, goal and global scenarios, the increments in forestland were proportionally divided among the different AEZs according to their availability of agriculture land (cropland plus livestock land). In other words, in a region r, the AEZs with greater amount of agriculture land were addressed with higher values of forestland increments.

ICES-AEZ results from the implementation of the restoration scenarios (i.e., pledged, goal and global scenarios) were compared with the baseline scenario to evaluate relative changes in land prices, total production and market prices of land intensive sectors (forestry, crops and livestock grazing). Likewise, impacts on regional GDP were also assessed.

4.3 Results and discussion

4.3.1 Effects on land prices

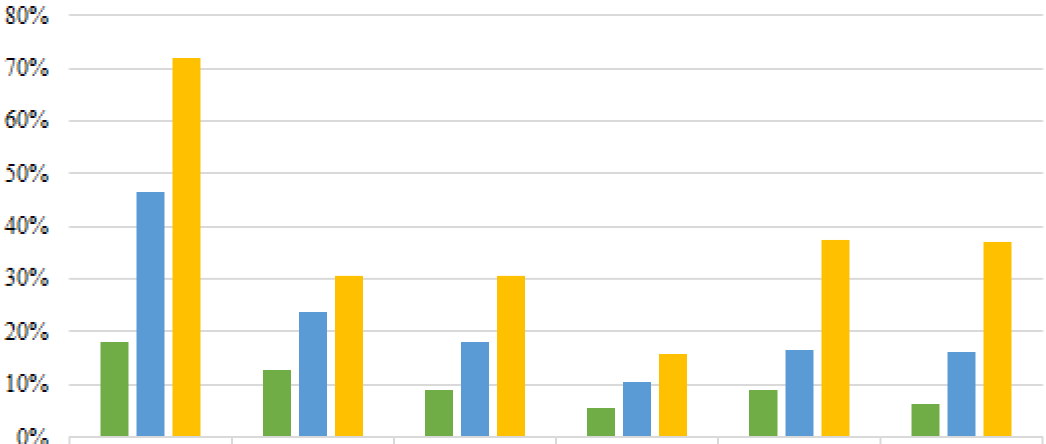
Figures 4.1 and 4.2 present, respectively, the impacts on land prices for the regions committed and not committed to Bonn Challenge's initiative:



	B_Africa	B_Asia	B_LatinAmer	B_NAmer
🟩 Pledged	35.72%	17.51%	21.26%	14.66%
🟦 Goal	105.94%	45.28%	47.25%	27.74%
🟨 Global	53.20%	30.96%	42.73%	36.63%

Figure 4.1 Land prices changes with respect to baseline for regions committed to Bonn Challenge's initiative.

Converting crop and livestock lands into forestland resulted in a non-marginal elevation of land prices for all regions committed to Bonn Challenge initiative. Scenarios and regions with higher rates of forestland expansion accounted for the higher elevations in land prices.



	NB_Africa	NB_Asia	NB_LatinAmer	NB_NAmer	Europe	Oceania
🟩 Pledged	18.08%	12.70%	8.81%	5.34%	8.83%	6.32%
🟦 Goal	46.34%	23.76%	17.94%	10.38%	16.61%	16.22%
🟨 Global	71.77%	30.57%	30.40%	15.79%	37.51%	36.87%

Figure 4.2 Land prices changes with respect to baseline for regions not committed to Bonn Challenge's initiative.

Goal scenario presented the higher land price changes for almost all regions under the restoration effort, except for B_NAmer which was more affected by the global scenario. It is important to highlight that, regardless the land prices increase in all regions, goal scenario was particularly disadvantageous to B_Africa. The strategy to extrapolate the ongoing commitments to achieve Bonn Challenge's final goal resulted in a heavy burden to the region, as it is liable to implement more than half of the 350-million restoration target (see Table 4.3).

In this sense, the global scenario appears as a more well-adjusted solution, sharing the restoration responsibility across the regions, including the ones that fall outside the initiative. In addition to that, this approach reveals to be more efficient than the others as it prioritizes regions with higher opportunities for forest restoration. Despite these positive aspects, this scenario still encumbers African region, B_Africa and NB_Africa, with the greatest share of the restoration effort (29% of all increase of forestland) and, consequently, the greatest rises in land prices.

From Figure 4.2, it is possible to verify that, for both Pledge and Goal scenarios, the increase of forestland in regions under Bonn Challenge's initiative also affected land prices in the other regions, indicating that the less availability of agricultural land pushes up the land prices even out of Bonn Challenge's regions borders.

Finally, while Pledged scenario presented the lowest impacts on land prices for all regions, its implementation fails to meet Bonn Challenge's objectives.

4.3.2 Effects on land intensive sectors and GDP

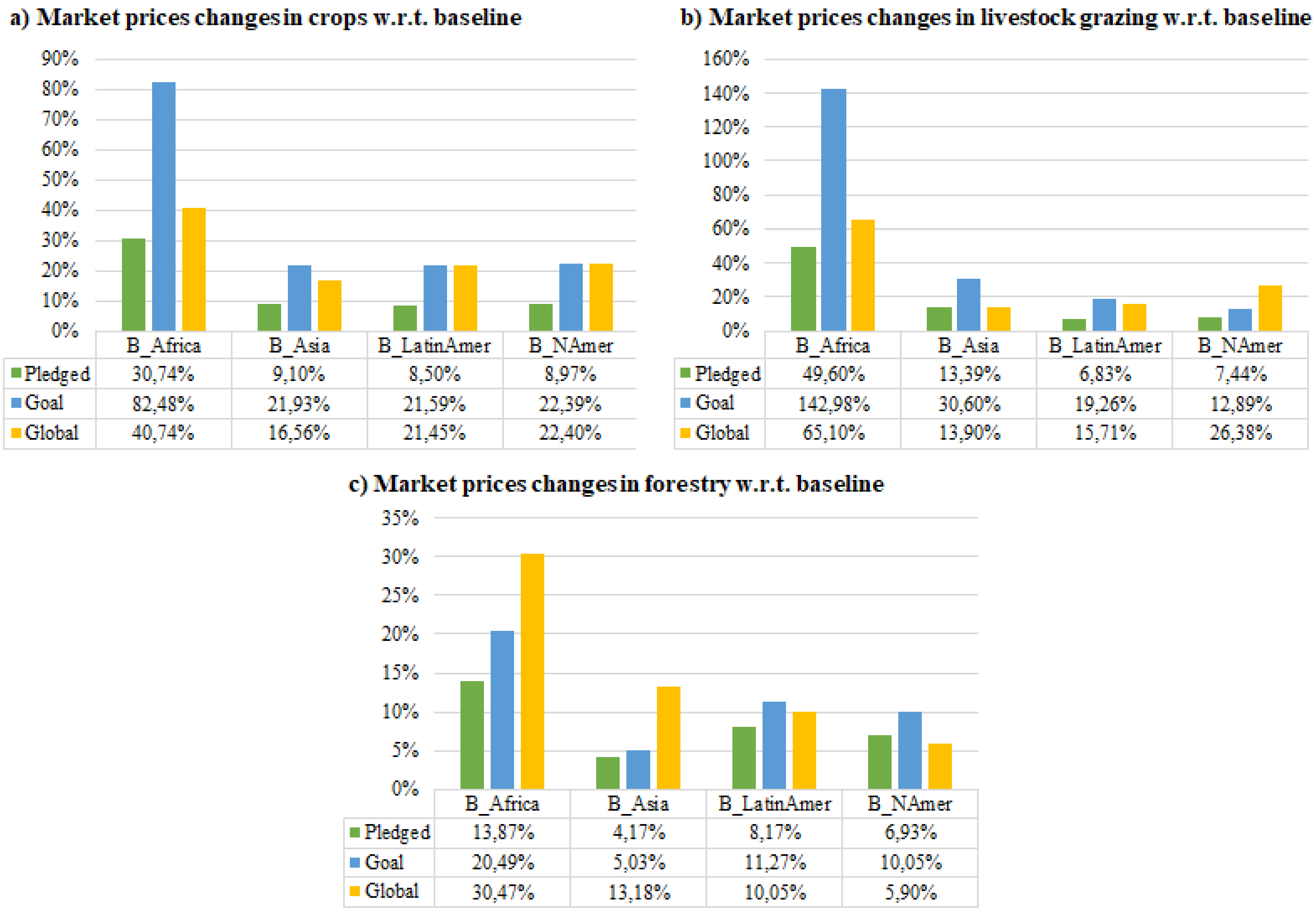
As it might be expected, the change on land availability among sectors and its consequent effects on land prices have directly impacted the market prices of land intensive sectors goods. Figure 4.3 presents the accumulated variation of market prices for crops, livestock grazing and forest products, compared with the baseline scenario.

Similarly to the effects on land prices, market prices also impacted by the increase of forest cover. B_Africa was again the mostly affected region, presenting higher levels of price elevation for all products, but in special on livestock ones, varying from 49.60% (pledge scenario) to 142.98% (goal scenario) of price elevation.

Crops and livestock products elevation in price in the other regions were not negligible, but still less expressive than the ones found in B_Africa, from two (global scenario) to four times lower (goal scenario). For forestry sector, it is interesting to note that, even with higher availability of land, market prices from forest products also increases, but to a lesser extent.

The effects of the restoration scenarios total production were different across the different regions, scenarios and sectors. As presented by Figure 4.4, crops production decreased for all scenarios in all regions, presenting the most negative results for B_Africa under goal scenario (13.60% reduction in total production). Livestock production fell in B_Africa and B_NAmer in all scenarios, achieving more pronounced reduction under global scenario (-25.21% and -24.52%, respectively). B_LatinAmer livestock production increased in all cases and B_Asia presented elevation in livestock production just for global scenario.

Forestry sector was the only one which presented increased production for all scenarios in all regions. Even considering the elevation in land prices and forestry products, these results were expected as forestland increased in all scenarios and regions under the Bonn Challenge initiative.



a) Market prices changes in crops w.r.t. baseline

	B_Africa	B_Asia	B_LatinAmer	B_NAmer
🟩 Pledged	30,74%	9,10%	8,50%	8,97%
🟦 Goal	82,48%	21,93%	21,59%	22,39%
🟨 Global	40,74%	16,56%	21,45%	22,40%

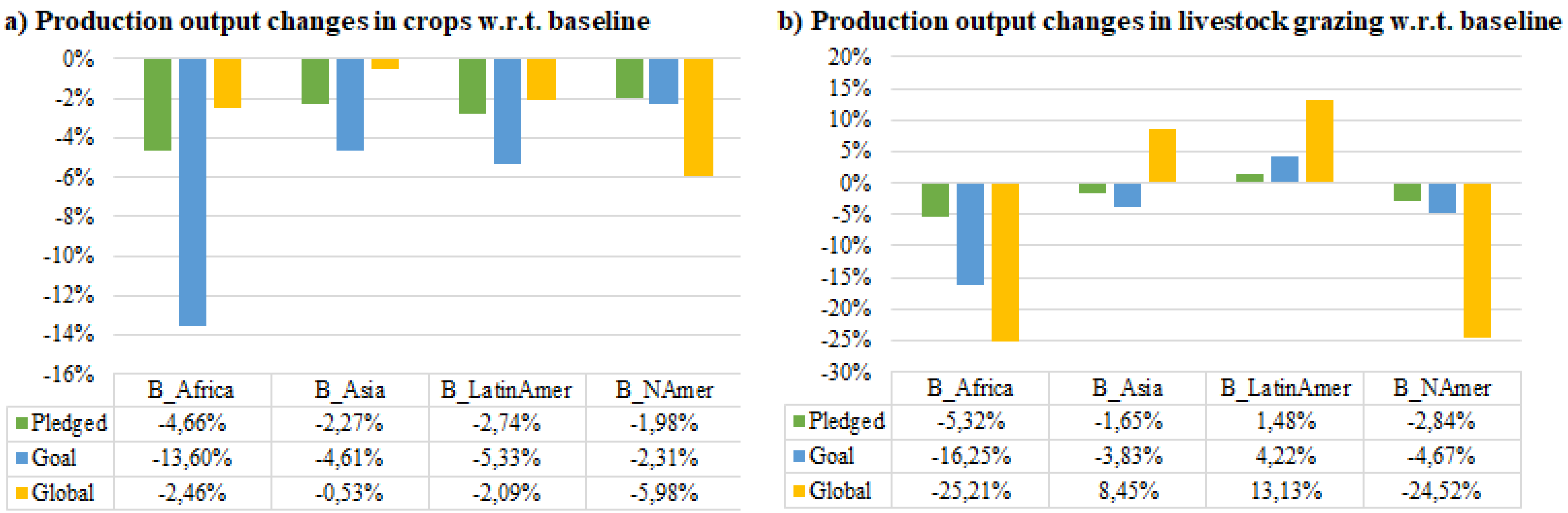
b) Market prices changes in livestock grazing w.r.t. baseline

	B_Africa	B_Asia	B_LatinAmer	B_NAmer
🟩 Pledged	49,60%	13,39%	6,83%	7,44%
🟦 Goal	142,98%	30,60%	19,26%	12,89%
🟨 Global	65,10%	13,90%	15,71%	26,38%

c) Market prices changes in forestry w.r.t. baseline

	B_Africa	B_Asia	B_LatinAmer	B_NAmer
🟩 Pledged	13,87%	4,17%	8,17%	6,93%
🟦 Goal	20,49%	5,03%	11,27%	10,05%
🟨 Global	30,47%	13,18%	10,05%	5,90%

Figure 4.3 Market prices changes in a) crops, b) livestock grazing and c) forestry sectors with respect to baseline.

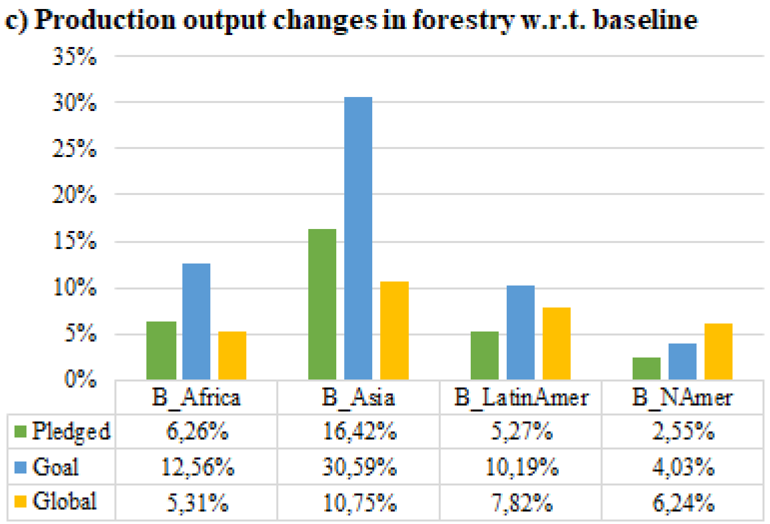


a) Production output changes in crops w.r.t. baseline

	B_Africa	B_Asia	B_LatinAmer	B_NAmer
🟩 Pledged	-4,66%	-2,27%	-2,74%	-1,98%
🟦 Goal	-13,60%	-4,61%	-5,33%	-2,31%
🟨 Global	-2,46%	-0,53%	-2,09%	-5,98%

b) Production output changes in livestock grazing w.r.t. baseline

	B_Africa	B_Asia	B_LatinAmer	B_NAmer
🟩 Pledged	-5,32%	-1,65%	1,48%	-2,84%
🟦 Goal	-16,25%	-3,83%	4,22%	-4,67%
🟨 Global	-25,21%	8,45%	13,13%	-24,52%



c) Production output changes in forestry w.r.t. baseline

	B_Africa	B_Asia	B_LatinAmer	B_NAmer
🟩 Pledged	6,26%	16,42%	5,27%	2,55%
🟦 Goal	12,56%	30,59%	10,19%	4,03%
🟨 Global	5,31%	10,75%	7,82%	6,24%

Figure 4.4 Production output changes in a) crops, b) livestock grazing and c) forestry sectors with respect to baseline.

Despite the economic shocks in land prices and land intensive sectors caused by the increase of forest cover, the effects on regional GDP were much less impactful. In all scenarios, the accumulated variation of GDP ranged from -0.8% to 0% in most regions, both under or out Bonn Challenge initiative. The only exception was Europe, which, even when included in the restoration effort, presented non-marginal elevation of GDP, from 2.5% (pledge scenario) up to 5.5% (global scenario).

4.4 Conclusion

In this chapter, by mean of an extended version of ICES model, it was possible to investigate the economic effects from the implementation of Bonn Challenge forest restoration initiative within a computable general equilibrium (CGE) framework. Three restoration scenarios were designed, simulated and then compared with a baseline scenario to evaluate relative changes in land prices, total production and market prices of land intensive sectors (forestry, crops and livestock grazing). Likewise, impacts on regional GDP were also assessed.

Results show that, the increasing of forestland at the cost of agriculture land (cropland and livestock grazing land) increases the price of land in general means, even in regions that were not initially committed with the forestation initiative. It was also verified that market prices from land intensive sectors (i.e., crops, livestock grazing and forestry) also increases with the increment of forestland.

With regard to the total productivity from these sectors, crops production decreases and forestry production increases for all regions and scenarios. Livestock production presented mixed behavior across different regions and scenarios.

Despite the economic shocks in land prices and land intensive sectors caused by the increase of forest cover, the effects on regional GDP were much less impactful. In all scenarios, the accumulated variation of GDP ranged from -0.8% to 0% in most regions, both under or out Bonn Challenge initiative. To conclude, in order to fairly share the economic impacts from Bonn Challenge's implementation, the restoration activities should be more evenly distributed across the world, reducing the burden of developing regions, in special African countries.

For further works, the use of a different land allocation approach which accounts for AEZs economic potentiality is encourage. A deeper investigation over the economic effects of Bonn Challenge's initiative over regions out of its scope is also recommended.

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Appendices

Appendix A Reforestation schedule

Table A.1 Reforestation schedule and costs.

Costs per Hectare – 48-year period			
Year	**OPERATION**	**Cost [BRL/ha]**	**Cost$^{(1)}$ [USD/ha]**
1	Construction & Maintenance of roads and firebreaks	R$ 270.00	$84.59
1	Construction & Maintenance of fences	R$ 300.00	$93.99
1	Slash-and-burn	R$ 360.00	$112.79
1	Total mechanized chemical weeding	R$ 300.00	$93.99
1	Subsoiling & Fertilization	R$ 800.00	$250.63
1	Leafcutter ants control	R$ 210.00	$65.79
1	Pit marking	R$ 310.00	$97.12
1	Planting and replanting	R$ 960.00	$300.76
1	Planting costs plus 10% (replanting)	R$ 1,400.00	$438.61
1	Manual weeding at the planting line	R$ 960.00	$300.76
1	Mechanized weeding between lines	R$ 320.00	$100.25
1	Manual chemical weeding for the planting line	R$ 280.00	$87.72
1	Selective manual cleaning at RL and APP	R$ 400.00	$125.32
1	Selective manual chemical weeding for APP & Legal Reserve	R$ 200.00	$62.66
1	Leafcutter ants control at RL and APP	R$ 120.00	$37.60
1	Pit digging at RL and APP	R$ 180.00	$56.39
1	Planting and replanting at RL and APP with 110 trees	R$ 380.00	$119.05
2	Roads and firebreaks maintenance	R$ 60.00	$18.80
2	Fence maintenance	R$ 20.00	$6.27
2	Manual weeding at the planting line	R$ 960.00	$300.76
2	Mechanized weeding between lines (3)	R$ 960.00	$300.76
2	Manual chemical weeding for the planting line (2)	R$ 560.00	$175.44
2	Leafcutter ants control (2)	R$ 380.00	$119.05
2	Replanting	R$ 380.00	$119.05
2	Pit digging (2)	R$ 440.00	$137.85
2	Selective manual cleaning at RL and APP	R$ 180.00	$56.39
2	Selective manual chemical weeding for APP & Legal Reserve (2)	R$ 270.00	$84.59
2	Leafcutter ants control at RL and APP (2)	R$ 90.00	$28.20
3	Roads and firebreaks maintenance	R$ 60.00	$18.80
3	Fence maintenance	R$ 20.00	$6.27
3	Mechanized weeding between lines (2)	R$ 640.00	$200.51
3	Manual chemical weeding for the planting line (2)	R$ 560.00	$175.44
3	Total manual chemical weeding	R$ 460.00	$144.11
3	Leafcutter ants control (2)	R$ 380.00	$119.05
3	Selective manual cleaning at RL and APP	R$ 240.00	$75.19
3	Selective manual chemical weeding for APP & Legal Reserve	R$ 160.00	$50.13
3	Leafcutter ants control at RL and APP (2)	R$ 90.00	$28.20
4	Roads and firebreaks maintenance	R$ 60.00	$18.80

4	Fence maintenance	R$ 20.00	$6.27
4	Total manual chemical weeding (2)	R$ 920.00	$288.23
4	Leafcutter ants control (2)	R$ 380.00	$119.05
4	Topdressing fertilization	R$ 640.00	$200.51
4	Selective manual chemical weeding for APP & Legal Reserve	R$ 160.00	$50.13
4	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
5	Roads and firebreaks maintenance	R$ 60.00	$18.80
5	Fence maintenance	R$ 20.00	$6.27
5	Total manual chemical weeding (2)	R$ 920.00	$288.23
5	Leafcutter ants control (2)	R$ 390.00	$122.18
6	Roads and firebreaks maintenance	R$ 60.00	$18.80
6	Fence maintenance	R$ 20.00	$6.27
6	Total manual chemical weeding (2)	R$ 920.00	$288.23
6	Leafcutter ants control (3)	R$ 540.00	$169.18
6	Chopping using product at the plot entrance*	R$ 640.00	$200.51
6	Tree branches pruning	R$ 180.00	$56.39
6	Pit digging	R$ 220.00	$68.92
6	Fertilization	R$ 440.00	$137.85
6	Enrichment/replanting	R$ 310.00	$97.12
6	Manual weeding at the planting line	R$ 960.00	$300.76
6	Mechanized weeding between lines	R$ 320.00	$100.25
6	Trees for interplanting/enrichment/replanting	R$ 280.00	$87.72
7	Roads and firebreaks maintenance	R$ 60.00	$18.80
7	Fence maintenance	R$ 20.00	$6.27
7	Mechanized weeding between lines (2)	R$ 640.00	$200.51
7	Total manual chemical weeding	R$ 460.00	$144.11
7	Leafcutter ants control (2)	R$ 360.00	$112.79
7	Manual weeding at the planting line	R$ 960.00	$300.76
7	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
8	Roads and firebreaks maintenance	R$ 60.00	$18.80
8	Fence maintenance	R$ 20.00	$6.27
8	Total manual chemical weeding	R$ 460.00	$144.11
8	Mechanized weeding between lines	R$ 320.00	$100.25
8	Leafcutter ants control (2)	R$ 380.00	$119.05
8	Manual weeding at the planting line	R$ 920.00	$288.23
9	Roads and firebreaks maintenance	R$ 60.00	$18.80
9	Fence maintenance	R$ 20.00	$6.27
9	Total mechanized chemical weeding (2)	R$ 780.00	$244.37
9	Leafcutter ants control (2)	R$ 380.00	$119.05
9	Selective manual chemical weeding for APP & Legal Reserve	R$ 200.00	$62.66
9	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
10	Roads and firebreaks maintenance	R$ 60.00	$18.80
10	Fence maintenance	R$ 20.00	$6.27
10	Total mechanized chemical weeding	R$ 390.00	$122.18
10	Mechanized weeding between lines	R$ 320.00	$100.25
10	Leafcutter ants control	R$ 190.00	$59.53
11	Roads and firebreaks maintenance	R$ 60.00	$18.80

11	Fence maintenance	R$ 20.00	$6.27
11	Total mechanized chemical weeding	R$ 390.00	$122.18
11	Mechanized weeding between lines	R$ 320.00	$100.25
11	Leafcutter ants control	R$ 190.00	$59.53
12	Roads and firebreaks maintenance	R$ 60.00	$18.80
12	Fence maintenance	R$ 20.00	$6.27
12	Total mechanized chemical weeding	R$ 390.00	$122.18
12	Total manual chemical weeding	R$ 460.00	$144.11
12	Manual cleaning at the planting line	R$ 380.00	$119.05
12	Mechanized weeding between lines	R$ 320.00	$100.25
12	Leafcutter ants control (2)	R$ 380.00	$119.05
12	Chopping using product at the plot entrance*	R$ 760.00	$238.10
12	Tree branches pruning	R$ 200.00	$62.66
12	Sprouting	R$ 180.00	$56.39
12	Pit digging	R$ 220.00	$68.92
12	Fertilization	R$ 440.00	$137.85
12	Enrichment/replanting	R$ 310.00	$97.12
12	Trees for enrichment/replanting	R$ 280.00	$87.72
13	Roads and firebreaks maintenance	R$ 60.00	$18.80
13	Fence maintenance	R$ 20.00	$6.27
13	Mechanized weeding between lines	R$ 320.00	$100.25
13	Total manual chemical weeding (2)	R$ 780.00	$244.37
13	Manual cleaning at the planting line	R$ 380.00	$119.05
13	Sprouting	R$ 160.00	$50.13
13	Leafcutter ants control (2)	R$ 380.00	$119.05
13	Fertilization with phosphorus, nitrogen & potassium	R$ 1,300.00	$407.28
13	Selective manual cleaning at RL and APP	R$ 240.00	$75.19
13	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
14	Roads and firebreaks maintenance	R$ 60.00	$18.80
14	Fence maintenance	R$ 20.00	$6.27
14	Total manual chemical weeding (2)	R$ 920.00	$288.23
14	Leafcutter ants control (2)	R$ 380.00	$119.05
15	Roads and firebreaks maintenance	R$ 60.00	$18.80
15	Fence maintenance	R$ 360.00	$112.79
15	Leafcutter ants control	R$ 190.00	$59.53
16	Roads and firebreaks maintenance	R$ 60.00	$18.80
16	Fence maintenance	R$ 20.00	$6.27
17	Roads and firebreaks maintenance	R$ 60.00	$18.80
17	Fence maintenance	R$ 20.00	$6.27
17	Selective manual cleaning at RL and APP	R$ 240.00	$75.19
17	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
18	Roads and firebreaks maintenance	R$ 60.00	$18.80
18	Fence maintenance	R$ 20.00	$6.27
18	Total manual chemical weeding	R$ 460.00	$144.11
18	Mechanized weeding between lines (2)	R$ 640.00	$200.51
18	Leafcutter ants control (2)	R$ 380.00	$119.05
18	Chopping using product at the plot entrance*	R$ 640.00	$200.51

18	Tree branches pruning	R$ 200.00	$62.66
18	Pit digging	R$ 220.00	$68.92
18	Fertilization	R$ 440.00	$137.85
18	Enrichment/replanting	R$ 310.00	$97.12
18	Manual weeding at the planting line	R$ 920.00	$288.23
18	Trees for enrichment/replanting	R$ 280.00	$87.72
19	Roads and firebreaks maintenance	R$ 60.00	$18.80
19	Fence maintenance	R$ 20.00	$6.27
19	Mechanized weeding between lines	R$ 320.00	$100.25
19	Total manual chemical weeding	R$ 390.00	$122.18
19	Manual cleaning at the planting line	R$ 380.00	$119.05
19	Sprouting	R$ 160.00	$50.13
19	Leafcutter ants control (2)	R$ 380.00	$119.05
19	Fertilization with phosphorus, nitrogen & potassium	R$ 1,300.00	$407.28
19	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
20	Roads and firebreaks maintenance	R$ 60.00	$18.80
20	Fence maintenance	R$ 20.00	$6.27
20	Total manual chemical weeding	R$ 460.00	$144.11
20	Mechanized weeding between lines	R$ 320.00	$100.25
20	Leafcutter ants control (2)	R$ 380.00	$119.05
21	Roads and firebreaks maintenance	R$ 60.00	$18.80
21	Fence maintenance	R$ 20.00	$6.27
21	Mechanized weeding between lines	R$ 320.00	$100.25
21	Total mechanized chemical weeding	R$ 390.00	$122.18
21	Leafcutter ants control (2)	R$ 380.00	$119.05
21	Selective manual chemical weeding for APP & Legal Reserve	R$ 200.00	$62.66
21	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
22	Roads and firebreaks maintenance	R$ 60.00	$18.80
22	Fence maintenance	R$ 20.00	$6.27
22	Total mechanized chemical weeding (2)	R$ 780.00	$244.37
22	Leafcutter ants control (2)	R$ 380.00	$119.05
23	Roads and firebreaks maintenance	R$ 60.00	$18.80
23	Fence maintenance	R$ 20.00	$6.27
23	Mechanized weeding between lines	R$ 320.00	$100.25
23	Total mechanized chemical weeding	R$ 390.00	$122.18
23	Leafcutter ants control	R$ 190.00	$59.53
24	Roads and firebreaks maintenance	R$ 60.00	$18.80
24	Fence maintenance	R$ 20.00	$6.27
24	Total manual chemical weeding (2)	R$ 920.00	$288.23
24	Mechanized weeding between lines	R$ 320.00	$100.25
24	Leafcutter ants control (2)	R$ 380.00	$119.05
24	Chopping using product at the plot entrance*	R$ 640.00	$200.51
24	Tree branches pruning	R$ 200.00	$62.66
24	Pit digging	R$ 220.00	$68.92
24	Fertilization	R$ 440.00	$137.85
24	Enrichment/replanting	R$ 310.00	$97.12
24	Manual weeding at the planting line	R$ 920.00	$288.23

24	Trees for interplanting/replanting	R$ 330.00	$103.39
25	Roads and firebreaks maintenance	R$ 60.00	$18.80
25	Fence maintenance	R$ 20.00	$6.27
25	Mechanized weeding between lines	R$ 320.00	$100.25
25	Total manual chemical weeding (2)	R$ 920.00	$288.23
25	Sprouting	R$ 320.00	$100.25
25	Leafcutter ants control (2)	R$ 380.00	$119.05
25	Fertilization with phosphorus, nitrogen & potassium	R$ 1,300.00	$407.28
25	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
26	Roads and firebreaks maintenance	R$ 60.00	$18.80
26	Fence maintenance	R$ 20.00	$6.27
26	Total manual chemical weeding (2)	R$ 920.00	$288.23
26	Leafcutter ants control (2)	R$ 380.00	$119.05
27	Roads and firebreaks maintenance	R$ 60.00	$18.80
27	Fence maintenance	R$ 20.00	$6.27
27	Leafcutter ants control	R$ 190.00	$59.53
28	Roads and firebreaks maintenance	R$ 60.00	$18.80
28	Fence maintenance	R$ 20.00	$6.27
28	Leafcutter ants control	R$ 190.00	$59.53
29	Roads and firebreaks maintenance	R$ 60.00	$18.80
29	Fence maintenance	R$ 20.00	$6.27
29	Selective manual chemical weeding for APP & Legal Reserve	R$ 200.00	$62.66
29	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
30	Roads and firebreaks maintenance	R$ 60.00	$18.80
30	Fence maintenance	R$ 360.00	$112.79
30	Total manual chemical weeding (2)	R$ 920.00	$288.23
30	Mechanized weeding between lines	R$ 320.00	$100.25
30	Leafcutter ants control (2)	R$ 380.00	$119.05
30	Chopping using product at the plot entrance*	R$ 640.00	$200.51
30	Tree branches pruning	R$ 200.00	$62.66
31	Roads and firebreaks maintenance	R$ 60.00	$18.80
31	Fence maintenance	R$ 20.00	$6.27
31	Mechanized weeding between lines	R$ 320.00	$100.25
31	Total manual chemical weeding (2)	R$ 920.00	$288.23
31	Sprouting	R$ 160.00	$50.13
31	Leafcutter ants control (2)	R$ 380.00	$119.05
31	Fertilization with phosphorus, nitrogen & potassium	R$ 1,110.00	$347.76
31	Selective manual chemical weeding for APP & Legal Reserve	R$ 200.00	$62.66
31	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
32	Roads and firebreaks maintenance	R$ 60.00	$18.80
32	Fence maintenance	R$ 20.00	$6.27
32	Total manual chemical weeding (2)	R$ 920.00	$288.23
32	Leafcutter ants control (2)	R$ 380.00	$119.05
33	Roads and firebreaks maintenance	R$ 60.00	$18.80
33	Fence maintenance	R$ 20.00	$6.27
33	Leafcutter ants control	R$ 180.00	$56.39
34	Roads and firebreaks maintenance	R$ 60.00	$18.80

34	Fence maintenance	R$ 20.00	$6.27
34	Leafcutter ants control	R$ 180.00	$56.39
35	Roads and firebreaks maintenance	R$ 60.00	$18.80
35	Fence maintenance	R$ 20.00	$6.27
35	Selective manual cleaning at RL and APP	R$ 400.00	$125.32
35	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
36	Roads and firebreaks maintenance	R$ 60.00	$18.80
36	Fence maintenance	R$ 20.00	$6.27
36	Total manual chemical weeding (2)	R$ 920.00	$288.23
36	Mechanized weeding between lines	R$ 320.00	$100.25
36	Leafcutter ants control (2)	R$ 380.00	$119.05
36	Chopping using product at the plot entrance*	R$ 640.00	$200.51
37	Roads and firebreaks maintenance	R$ 60.00	$18.80
37	Fence maintenance	R$ 20.00	$6.27
37	Mechanized weeding between lines	R$ 320.00	$100.25
37	Total manual chemical weeding (2)	R$ 920.00	$288.23
37	Sprouting	R$ 160.00	$50.13
37	Leafcutter ants control (2)	R$ 380.00	$119.05
37	Fertilization with phosphorus, nitrogen & potassium	R$ 1,300.00	$407.28
37	Selective manual chemical weeding for APP & Legal Reserve	R$ 200.00	$62.66
37	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
38	Roads and firebreaks maintenance	R$ 60.00	$18.80
38	Fence maintenance	R$ 20.00	$6.27
38	Total manual chemical weeding (2)	R$ 920.00	$288.23
38	Leafcutter ants control (2)	R$ 380.00	$119.05
39	Roads and firebreaks maintenance	R$ 60.00	$18.80
39	Fence maintenance	R$ 20.00	$6.27
39	Leafcutter ants control	R$ 180.00	$56.39
40	Roads and firebreaks maintenance	R$ 60.00	$18.80
40	Fence maintenance	R$ 360.00	$112.79
40	Leafcutter ants control	R$ 180.00	$56.39
41	Roads and firebreaks maintenance	R$ 60.00	$18.80
41	Fence maintenance	R$ 20.00	$6.27
41	Selective manual cleaning at RL and APP	R$ 400.00	$125.32
41	Leafcutter ants control at RL and APP	R$ 90.00	$28.20
42	Roads and firebreaks maintenance	R$ 60.00	$18.80
42	Fence maintenance	R$ 20.00	$6.27
42	Total manual chemical weeding (2)	R$ 920.00	$288.23
42	Mechanized weeding between lines	R$ 320.00	$100.25
42	Leafcutter ants control (2)	R$ 380.00	$119.05
42	Chopping using product at the plot entrance*	R$ 640.00	$200.51
42	Tree branches pruning	R$ 200.00	$62.66
43	Roads and firebreaks maintenance	R$ 60.00	$18.80
43	Fence maintenance	R$ 20.00	$6.27
43	Mechanized weeding between lines	R$ 320.00	$100.25
43	Total manual chemical weeding (2)	R$ 920.00	$288.23
43	Sprouting	R$ 160.00	$50.13

43	Leafcutter ants control (2)	R$ 380.00	$119.05
44	Roads and firebreaks maintenance	R$ 60.00	$18.80
44	Fence maintenance	R$ 20.00	$6.27
44	Leafcutter ants control	R$ 190.00	$59.53
45	Roads and firebreaks maintenance	R$ 60.00	$18.80
45	Construction & Maintenance of fences	R$ 20.00	$6.27
45	Leafcutter ants control	R$ 190.00	$59.53
46	Roads and firebreaks maintenance	R$ 60.00	$18.80
46	Fence maintenance	R$ 20.00	$6.27
47	Roads and firebreaks maintenance	R$ 60.00	$18.80
47	Fence maintenance	R$ 20.00	$6.27
47	Total manual chemical weeding	R$ 460.00	$144.11
47	Leafcutter ants control	R$ 190.00	$59.53
48	Roads and firebreaks maintenance	R$ 60.00	$18.80
48	Fence maintenance	R$ 20.00	$6.27
48	Total manual chemical weeding	R$ 460.00	$144.11
48	Mechanized weeding between lines	R$ 320.00	$100.25
48	Leafcutter ants control	R$ 190.00	$59.53
48	Chopping using product at the plot entrance*	R$ 640.00	$200.51
48	Tree branches pruning	R$ 200.00	$62.66

(1)Considering an exchange rate of 3.1919 BRL/USD, equals to 1-year average rate, from 01/2017 to 12/2017 (Central Bank of Brazil, 2018a);

Appendix B Bonn Challenge commitments

Table B.1 Restoration commitments officially pledged under Bonn Challenge initiative.

Commitments(1)(2)	**Commitment Year**	**Target Year**	**Pledged Area [Mha]**
Argentina	2015	2020	1.00
Armenia	2018	2030	0.26
Bangladesh	2017	2020	0.75
Benin	2016	2020	0.20
	2016	2030	0.30
Brazil	2011	2020	1.00
	2016	2030	12.00
Burundi	2015	2020	2.00
Cameroon	2017	2030	12.06
Central African Republic	2016	2020	1.00
	2016	2030	2.50
Chad	2017	2030	5.00
Chile	2015	2020	0.50
Colombia	2014	2020	1.00
Costa Rica	2012	2020	1.00
Côte d'Ivoire	2016	2030	5.00
Democratic Republic of the Congo	2014	2020	8.00
Dominican Republic	2018	2020	0.07
	2018	2030	0.12

Ecuador	2014	2020	0.50
El Salvador	2012	2020	1.00
eSwatini(3)	2018	2030	0.50
Ethiopia	2014	2020	15.00
Georgia	2018	2030	0.01
Ghana	2015	2030	2.00
Guatemala	2014	2020	1.20
	2016	2020	0.04
Guinea	2016	2030	2.00
Honduras	2015	2020	1.00
India	2015	2020	13.00
	2015	2030	8.00
Indonesia(4)	2015	2020	1.00
Kazakhstan	2018	2030	1.50
Kenya	2016	2030	5.10
Kyrgyzstan	2018	2030	0.32
Liberia	2015	2020	1.00
Madagascar	2015	2020	2.50
	2015	2030	1.50
Malawi	2016	2020	2.00
	2016	2030	2.50
Mexico	2014	2020	8.47
	2015	2030	0.35
	2015	2030	0.30
	2015	2030	0.40
	2017	2030	0.18
Mongolia	2017	2030	0.60
Mozambique	2016	2030	1.00
Nicaragua	2015	2020	2.70
Niger	2015	2020	3.20
Nigeria	2017	2030	4.00
Pakistan	2015	2020	0.35
	2017	2020	0.10
	2018	2020	0.25
Panama	2016	2020	1.00
Peru	2014	2020	3.20
Republic of the Congo	2015	2030	2.00
Rwanda	2011	2020	2.00
Sri Lanka	2017	2020	0.20
Tajikistan	2018	2030	0.07
Tanzania	2018	2030	5.20
Uganda	2014	2020	2.50
United States	2011	2020	15.00
Uzbekistan	2018	2030	0.50
		Total	**169.00**

(1)Source: GPFLR and IUCN (2018);

(2)Benin, Brazil, Central African Republic, Dominican Republic, Guatemala, India, Madagascar, Malawi, Mexico and Pakistan presented more than one national or regional pledge;

(3)Former Swaziland;

(4)This pledge was made by Asia Pulp & Paper Co. Ltd. , a private Indonesian company based in Jakarta. Despite the company presence in other Asian countries, such as China, in the context of this exercise, the restoration pledge was addressed only for Indonesia.

Appendix C The ICES Model

ICES is a dynamic, multi-sector, multi-country model based on the core structure of GTAP (Global Trade Analysis Project) model (Hertel, 1997). As in all CGE models, ICES makes use of the Walrasian perfect competition paradigm to simulate market adjustment processes, although the inclusion of some elements of imperfect competition is also possible.

Each industry is modeled as a cost-minimizing representative firm. On the other hand, output prices are given by average production costs. The production functions are specified via a series of nested Constant Elasticity of Substitutions (CES) functions. The substitution between domestically-produced and imported goods is imperfect, following the approach suggested by Armington (1969) who treats goods of different origin as distinct and non-homogeneous. Figure C.1 presents model's production tree:

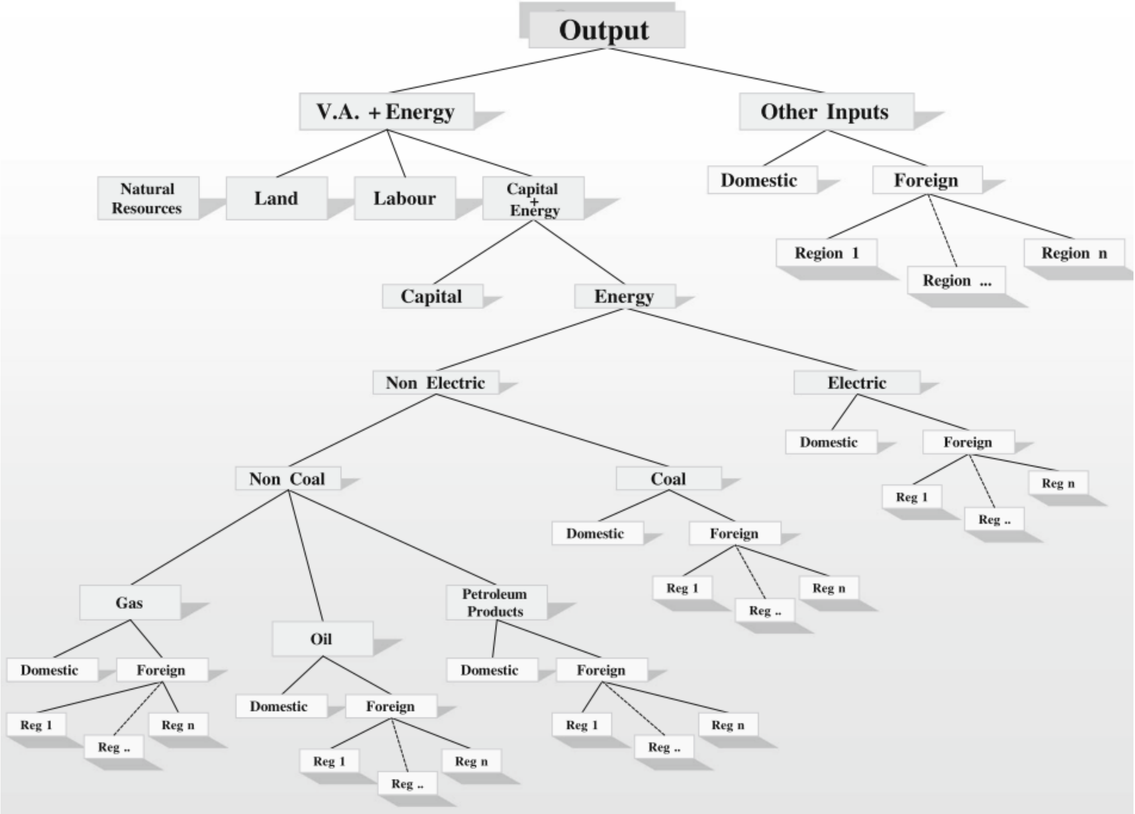


Figure C.1 Tree structure for industrial production processes of the ICES model.
Source: Bosello et al. (2012).

A representative consumer in each region receives income, defined as the service value of national primary factors (capital, labor, land and natural resources). Capital and labor are perfectly mobile domestically, but immobile internationally. Land and natural resources, in turn, are industry-specific. This income is used to finance consumers preferences over three classes of expenditure: private consumption, public consumption, and savings (Figure C.2). The expenditure shares are generally fixed, which amounts to saying that the top-level utility function has a Cobb-Douglas specification.

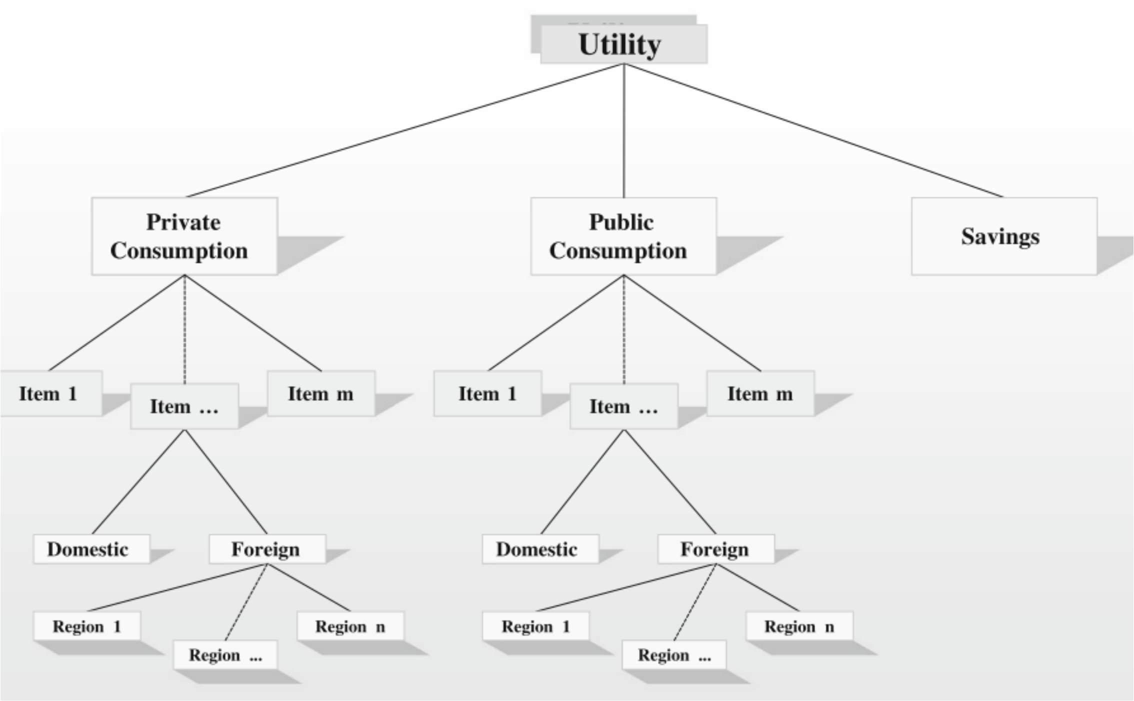


Figure C.2 Tree structure for final demand of the ICES model.
Source: Bosello et al. (2012).

Public consumption is split in a series of alternative consumption items, again according to a Cobb-Douglas specification. However, almost all expenditure is concentrated just in non-market services. Private consumption is analogously split in a series of alternative composite Armington aggregates. However, the functional specification used at this level is the Constant Difference in Elasticities form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods.

Investment is internationally mobile: savings from all regions are pooled and then investment is allocated to achieve equality of expected rates of return to capital. In this way, savings and investments are equalized at the world, but not at the regional level. Because of accounting identities, any financial imbalance mirrors a trade deficit or surplus in each region.

ICES recursive-dynamic engine can reproduce dynamic economic growths based on endogenous investment decisions, generating a sequence of static equilibria under myopic behavior (when agents are too focused on current levels of earnings), linked between time periods by capital and international debt accumulation. Two factors endogenously drive investment and its international allocation: the equalization of the expected rate of return to capital and the international GDP differentials. Thus, a region can attract more investment and increase the rate of growth of its capital stock when its GDP and its rate of return to capital are relatively higher than those of its competitors. For a more information about the model, the reader can refer to Eboli et al. (2010), Bosello et al. (2012) and Parrado and De Cian (2014).

Appendix D Regional aggregation

Table D.1 Regional aggregation from GTAP 8.1 database original geographic regions.

Aggregated Region	GTAP 8.1 Countries/Regions	GTAP Code
B_Africa	Cameroon	CMR
	Cote d'Ivoire	CIV
	Ghana	GHA
	Nigeria	NGA
	Rest of Western Africa	XWF
	Central Africa	XCF
	South Central Africa	XAC
	Ethiopia	ETH
	Kenya	KEN
	Madagascar	MDG
	Malawi	MWI
	Mozambique	MOZ
	Tanzania	TZA
	Uganda	UGA
	Rest of Eastern Africa	XEC
	Rest of South African Customs Union	XSC
NB_Africa	Egypt	EGY
	Morocco	MAR
	Tunisia	TUN
	Rest of North Africa	XNF
	Senegal	SEN
	Mauritius	MUS
	Zambia	ZMB
	Zimbabwe	ZWE
	Botswana	BWA
	Namibia	NAM
	South Africa	ZAF
B_Asia	Mongolia	MNG
	Indonesia	IDN
	Bangladesh	BGD
	India	IND
	Pakistan	PAK
	Sri Lanka	LKA
	Kazakhstan	KAZ
	Kyrgyzstan	KGZ
	Rest of Former Soviet Union	XSU
	Armenia	ARM
	Georgia	GEO

NB_Asia	China	CHN
	Hong Kong	HKG
	Japan	JPN
	South Korea	KOR
	Taiwan	TWN
	Rest of East Asia	XEA
	Cambodia	KHM
	Laos	LAO
	Malaysia	MYS
	Philippines	PHL
	Singapore	SGP
	Thailand	THA
	Vietnam	VNM
	Rest of Southeast Asia	XSE
	Nepal	NPL
	Rest of South Asia	XSA
	Azerbaijan	AZE
	Bahrain	BHR
	Iran	IRN
	Israel	ISR
	Kuwait	KWT
	Oman	OMN
	Qatar	QAT
	Saudi Arabia	SAU
	Turkey	TUR
	United Arab Emirates	ARE
	Rest of Western Asia	XWS
B_LatinAmer	Mexico	MEX
	Argentina	ARG
	Brazil	BRA
	Chile	CHL
	Colombia	COL
	Ecuador	ECU
	Peru	PER
	Costa Rica	CRI
	Guatemala	GTM
	Honduras	HND
	Nicaragua	NIC
	Panama	PAN
	El Salvador	SLV
NB_LatinAmer	Bolivia	BOL
	Paraguay	PRY
	Uruguay	URY
	Venezuela (Bolivarian Republic of)	VEN
	Rest of South America	XSM
	Rest of Central America	XCA
	Caribbean	XCB
B_NAmer	United States of America	USA
NB_NAmer	Canada	CAN
	Rest of North America	XNA
Europe	Austria	AUT
	Belgium	BEL

	Cyprus	CYP
	Czech Republic	CZE
	Denmark	DNK
	Estonia	EST
	Finland	FIN
	France	FRA
	Germany	DEU
	Greece	GRC
	Hungary	HUN
	Ireland	IRL
	Italy	ITA
	Latvia	LVA
	Lithuania	LTU
	Luxembourg	LUX
	Malta	MLT
	Netherlands	NLD
	Poland	POL
	Portugal	PRT
	Slovakia	SVK
	Slovenia	SVN
	Spain	ESP
	Sweden	SWE
	United Kingdom	GBR
	Switzerland	CHE
	Norway	NOR
	Rest of EFTA	XEF
	Albania	ALB
	Bulgaria	BGR
	Belarus	BLR
	Croatia	HRV
	Romania	ROU
	Russian Federation	RUS
	Ukraine	UKR
	Rest of Eastern Europe	XEE
	Rest of Europe	XER
Oceania	Australia	AUS
	New Zealand	NZL
	Rest of Oceania	XOC
RestofWorld	Rest of the World	XTW

Appendix E Forestland, cropland and livestock land distribution

Table E.1 Forestland distribution across AEZs and regions [in kha].

	B_Africa	NB_Africa	B_Asia	NB_Asia	B_LatinAmer	NB_LatinAmer	B_NAmer	NB_NAmer	Europe	Oceania	RestofWorld	**Total**
AEZ1	86,013	2,597	5,678	27,728	10,292	712	0	0	0	52,127	0	**185,146**
AEZ2	48,998	7,412	2,325	0	10,409	666	0	0	0	55,632	0	**125,441**
AEZ3	89,341	36,010	16,679	416	38,266	4,085	0	0	0	38,067	0	**222,863**
AEZ4	149,969	13,342	14,074	15,399	65,668	16,635	0	0	201	8,523	0	**283,812**
AEZ5	137,830	1,236	5,841	50,735	112,050	21,089	0	0	0	2,272	0	**331,052**
AEZ6	136,006	1,006	38,887	35,326	163,150	27,050	0	0	0	4,727	0	**406,155**
AEZ7	881	53,044	88,429	118,135	78,201	3,084	67,929	2,795	6,091	251,369	0	**669,957**
AEZ8	2,271	38,024	17,351	66,080	32,705	7,895	25,319	2,087	14,129	23,061	0	**228,921**
AEZ9	16,435	25,631	3,605	49,919	31,941	5,564	12,335	27,284	43,414	15,860	0	**231,986**
AEZ10	8,593	9,369	4,720	50,106	19,276	2,408	70,283	22,858	121,780	10,654	0	**320,047**
AEZ11	3,550	1,030	2,587	64,554	8,425	1,430	52,809	503	35,953	11,816	0	**182,658**
AEZ12	738	0	2,154	70,639	40,408	5,149	57,152	0	7,604	16,950	0	**200,795**
AEZ13	0	0	32,921	12,211	7,686	2,347	10,144	1,637	6,267	0	0	**73,214**
AEZ14	0	0	20,117	3,732	10,879	334	28,443	18,275	190,976	0	0	**272,755**
AEZ15	0	0	6,697	21,466	6,365	437	28,829	34,274	201,925	605	0	**300,597**
AEZ16	0	0	1,122	9,818	5,874	229	2,332	799	5,473	2,300	0	**27,948**
AEZ17	0	0	0	534	1,789	0	0	0	0	1,017	0	**3,340**
AEZ18	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**680,625**	**188,701**	**263,186**	**596,801**	**643,383**	**99,114**	**355,575**	**110,512**	**633,813**	**494,976**	**0**	**4,066,684**

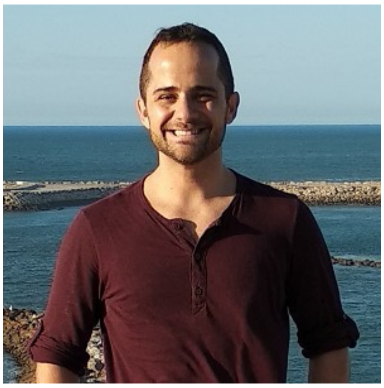
Table E.2 Cropland distribution across AEZs and regions [in kha].

	B_Africa	NB_Africa	B_Asia	NB_Asia	B_LatinAmer	NB_LatinAmer	B_NAmer	NB_NAmer	Europe	Oceania	RestofWorld	**Total**
AEZ1	14,049	2,806	6,138	2,544	1,441	43	0	0	0	29	0	**27,050**
AEZ2	38,088	3,661	13,408	25	1,883	42	0	0	0	269	0	**57,377**
AEZ3	26,856	7,883	75,438	262	8,915	363	0	0	0	130	0	**119,848**
AEZ4	43,565	5,310	35,436	16,833	16,398	3,418	0	0	17	132	0	**121,109**
AEZ5	39,036	1,686	18,370	22,567	29,034	7,525	0	0	0	125	0	**118,343**
AEZ6	14,914	570	58,089	26,651	23,141	3,250	0	0	0	1,969	0	**128,582**
AEZ7	335	4,231	26,336	16,812	7,409	124	32,148	7,124	4,205	4,362	0	**103,085**
AEZ8	591	5,907	26,099	54,021	7,821	402	25,660	4,909	46,135	9,824	0	**181,370**
AEZ9	1,373	12,749	14,969	41,657	10,357	622	13,235	7,163	61,538	8,652	0	**172,315**
AEZ10	2,451	11,834	3,954	26,850	12,105	414	46,818	6,821	114,999	2,648	0	**228,895**
AEZ11	2,254	365	1,884	26,240	8,175	238	33,405	29	32,294	1,362	0	**106,245**
AEZ12	243	0	1,422	38,133	26,558	5,324	13,618	0	5,720	1,619	0	**92,637**
AEZ13	0	0	17,727	2,493	250	32	1,856	2,467	3,395	0	0	**28,220**
AEZ14	0	0	3,803	1,535	427	28	322	1,252	9,251	0	0	**16,619**
AEZ15	0	0	684	2,332	421	22	24	7,327	21,212	0	0	**32,021**
AEZ16	0	0	107	688	393	7	2	372	801	10	0	**2,379**
AEZ17	0	0	0	27	3	0	0	0	0	2	0	**31**
AEZ18	0	0	0	0	1	0	0	0	0	0	0	**1**
Total	**183,755**	**57,003**	**303,864**	**279,668**	**154,733**	**21,851**	**167,088**	**37,463**	**299,568**	**31,133**	**0**	**1,536,127**

Table E.3 Livestock land distribution across AEZs and regions [in kha].

	B_Africa	NB_Africa	B_Asia	NB_Asia	B_LatinAmer	NB_LatinAmer	B_NAmer	NB_NAmer	Europe	Oceania	RestofWorld	**Total**
AEZ1	144,371	5,828	946	19,805	4,188	682	0	0	0	28,463	0	**204,283**
AEZ2	81,760	6,570	944	21	3,807	1,339	0	0	0	21,535	0	**115,976**
AEZ3	88,863	21,313	4,201	36	13,437	1,599	0	0	0	4,444	0	**133,894**
AEZ4	129,592	15,426	1,642	1,032	26,391	9,243	0	0	29	1,417	0	**184,771**
AEZ5	51,111	987	1,090	3,125	107,277	26,395	0	0	0	67	0	**190,052**
AEZ6	12,366	884	1,812	3,764	65,481	13,060	0	0	0	499	0	**97,864**
AEZ7	4,371	119,960	166,985	77,946	82,518	1,912	142,603	4,676	11,445	153,868	0	**766,284**
AEZ8	1,909	39,316	30,508	102,223	17,431	5,555	36,071	2,277	20,013	18,923	0	**274,227**
AEZ9	7,422	29,828	1,748	23,727	10,900	3,927	5,371	3,399	20,080	10,862	0	**117,263**
AEZ10	11,034	13,636	1,761	10,669	7,918	1,589	16,704	1,663	46,600	5,890	0	**117,463**
AEZ11	2,031	1,712	738	20,299	7,054	2,023	11,782	16	18,752	7,775	0	**72,180**
AEZ12	94	0	289	25,936	42,769	23,270	6,943	0	6,155	8,119	0	**113,574**
AEZ13	0	0	86,397	36,195	14,594	292	7,379	2,151	2,489	0	0	**149,498**
AEZ14	0	0	37,789	39,145	7,644	383	2,112	888	9,699	0	0	**97,660**
AEZ15	0	0	5,171	28,471	4,686	120	144	5,346	18,590	330	0	**62,858**
AEZ16	0	0	387	8,499	3,931	62	2	277	1,793	2,084	0	**17,035**
AEZ17	0	0	0	251	468	0	0	0	0	145	0	**864**
AEZ18	0	0	0	0	159	0	0	0	0	0	0	**159**
Total	**534,923**	**255,459**	**342,410**	**401,143**	**420,654**	**91,450**	**229,111**	**20,693**	**155,644**	**264,420**	**0**	**2,715,906**

ABOUT THE AUTHOR



Remo Augusto Padovezi Filleti was born in Santa Bárbara d'Oeste, Brazil, in 15th January 1988. He obtained a B.Sc. in Automation & Control Engineering from the State University of Campinas (Unicamp) in 2012, and a M.Sc. in Production Engineering in 2015 from the São Carlos School of Engineering - University of São Paulo (EESC-USP), both in Brazil. His M.Sc. dissertation was focused of the Life Cycle Assessment (LCA) of industrial processes, particularly machining processes.

In 2015, he started his Ph.D. in Science and Management of Climate Change, evaluating the potential economic and mitigation impacts from forestation projects and initiatives. Despite having worked mostly with industrial process, he recognizes the importance of forests towards a greener and climate-safe global economy.

Among his experiences, Remo was member of the Laboratory for Advanced Process and Sustainability (LAPRAS) from EESC-USP, where he developed a LCA hybrid model combined with a real-time monitoring system to implement LCA studies for manufacturing unit processes. He also contributed to LAPRAS's knowledge management by supervising the implementation of laboratory's first Standard Operating Procedures (SOPs). He is currently engaged as a Research Affiliate at the Foundation Euro-Mediterranean Centre on Climate Change, based in Venice at Ca'Foscari University of Venice (CMCC@Ca'Foscari). He is also member of Environmental Technology and Green Economy team (aka Green Challenges team) from Ca'Foscari research for Global Challenges initiative.

In the future, he intends to connect the competences developed during the M.Sc. and the Ph.D. regarding life cycle assessment, industrial processes, forestry and climate change to work with issuing and audition procedures for carbon emission permits (aka carbon credits).

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